EXECUTIVE FUNCTION PROCESSES: INHIBITION, WORKING MEMORY, PLANNING AND ATTENTION IN CHILDREN AND YOUTH WITH ATTENTION DEFICIT HYPERACTIVITY DISORDER

A Dissertation

by

MONICA EILEEN WOLFE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2004

Major Subject: School Psychology

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ABSTRACT

Executive Function Processes: Inhibition, Working Memory, Planning and Attention in Children and Youth with Attention Deficit Hyperactivity Disorder. (December 2004).

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This study examines the roles of inhibition, attention, working memory, and planning in youth with and without ADHD. As conceptualized in theories of attention, inhibition, and working memory, difficulties with these executive processes interact to manifest in the behavioral syndrome(s) of ADHD. Barkley (1997) proposed disinhibition as the primary deficit of ADHD. Rapport, Chung, Shore, Denney, & Isaacs, (2000) theorized that ADHD results from a primary deficit in working memory. Mirsky (1987) proposed a model of attention which children with ADHD have deficits in abilities to focus/execute, encode and sustain attention. Posner and Petersen (1990) proposed that three attentional networks are responsible for attentional processes and those children with ADHD have deficits in the vigilance network. To investigate the contributions of inhibition, working memory, attention, and planning in executive dysfunction in children with ADHD, measures were selected from factor analytic studies.

Children with ADHD-Combined Type demonstrated poorer inhibition and working memory than children with no diagnosis after controlling for IQ effects. No differences in planning and attention were indicated after controlling for IQ effects.

However, a predictive discriminant analysis indicated that none of the executive processes contributed to the prediction of group membership. Given correlational and predictive discriminant analysis results, further analyses were conducted to investigate the contribution of the measures selected for the domains. The theoretical model did not represent a good fit of the data. A three-factor model indicated the best representation suggesting that inhibition and attention were not separable. There were no group differences with the revised measurement model for inhibition/attention, working memory and planning. Taken together, results indicated measures originally selected to tap executive function may not be clean measures of inhibition, working memory, planning, or attention processes. In addition, recently proposed theories overlap and conceptualize the multiple constructs involved in ADHD with a variety of methodologies, further contributing to difficulties in interpreting results and measurement issues.

DEDICATION

For a couple of years I had the pleasure of working with the families and the children who participated in the Memory, Attention, and Planning Study. Without their willingness to participate and trust, this research would not have been possible. I would like to dedicate this dissertation to those families as well as my own.

ACKNOWLEDGMENTS

I would like to express my gratitude and thanks to my family, which includes the Texas A&M family. When considering the A&M family, I was extremely privileged to work with and learn from the faculty and staff at Texas A&M. Specifically, I would like to thank Drs. Michael Ash and Cynthia Riccio for their kindness, guidance, and encouragement for the entire five years and for their willingness to be my co-chairs. I am deeply appreciative to Dr. Riccio for her mentorship, generosity with her time and support, and her patience. Her research and clinical expertise, determination, and optimism, have been invaluable. Dr. Ash was instrumental in my gaining acceptance into the School Psychology Program, which has been an immensely rewarding experience. I am also especially grateful to my remaining committee members, Drs. Constance Fournier and Antonio Cepeda-Benito who have given freely of their time and expertise.

In addition, I would like to express my gratitude to my fellow graduate students who gave up many Saturdays and evenings, evaluated children, interviewed parents, wrote reports, and offered their moral support. I would also like to thank Dr. Victor Willson for his assistance and guidance in statistical analysis. The study was funded, in part, by The National Academy of Neuropsychology and their support was greatly appreciated. I would also like to thank Dr. William Rae for providing clinic space and student staff to facilitate data collection.

Finally, I would like to thank my husband, John and my daughters, Sabrina and Amanda for their support, encouragement, and most of all, their sense of humor.

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CHAPTER I

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) affects 4%-5% of children (Barkley, 1998). Children with ADHD are hypothesized to have impairments in executive functions including attention, inhibition, planning and working memory (Tannock, 1998). ADHD is characterized by symptoms of inattention, hyperactivity, and impulsivity. The current nosology includes four possible diagnoses: predominantly inattentive type, predominantly hyperactive/impulsive type, combined type, and not otherwise specified type (see Appendix A; American Psychiatric Association [APA], 1994, 2000). To diagnose the disorder, a designated number of symptoms determined from a list of typical behaviors must be present. The symptoms must be present before seven years of age in two or more settings causing significant problems in social, academic, or occupational areas. Finally, these symptoms cannot be better explained by other clinical disorders. Adolescents and adults can be considered "in partial remission" if they no longer meet the full criteria yet some symptoms persist (APA, 2000).

Boys are more frequently diagnosed at a rate of 3:1 to 9:1 (APA, 1994, 2000). Of those children diagnosed with ADHD, 30% -70% will continue to be affected by the disorder into adulthood (e.g. Barkley, Fisher, Edelbrock, & Smallish, 1990). Symptoms of ADHD may be related to age, with some symptoms remitting with maturity; however, the individual may continue to display symptoms even though they no longer meet the

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This dissertation follows the style and format of *Journal of Educational Psychology*.

criteria for a diagnosis (Biederman, Mick, & Faraone, 2000).

The heterogeneity of children and adolescents with ADHD has led to research into different etiologies, development, and neurobiological findings among subtypes. Researchers have explored the symptoms and defined characteristics of ADHD from neuroanatomical, neurochemical, neuropsychological, and cognitive perspectives.

Individuals with the inattentive type appear to have a greater co-occurrence of learning problems, anxiety, and depression and are more likely to receive help in school (Faraone, Biederman, Weber, & Russell, 1998). Individuals with combined type are referred more frequently for psychological intervention (Faraone et al., 1998; Gaub & Carlson, 1997). The increased referrals may be because children and adolescents with the combined type tend to have a greater incidence of behavior and conduct problems, poor family and peer relations, and early substance use. It is thought that the hyperactive type diagnosis may be a precursor to the combined type. The hyperactive type occurs less frequently and this type is identified more often in young children (Hart et al., 1995).

At this time, there is no one theory of ADHD that is widely accepted. Historically, ADHD was thought to have excessive motor movement as the primary deficit and was called “hyperkinesis” (APA, 1968). Later, ADHD was defined by lack of attention and impulse control as the hallmarks of the disorder (APA, 1980). Some prominent researchers are calling for yet another definition of the primary deficits in ADHD (e.g., Barkley, 1997, 1998: Mirsky, 1987; Voeller, 1991).

From their various theories, Barkley (1997) proposed disinhibition as the primary deficit of ADHD that contributes to difficulties in working memory and executive functions. In contrast, Mirsky (1987) proposed a four-factor model of attention such that children and adolescents with ADHD have shown deficits in three out of the four factors. He proposed that the multi-component construct of attention would manifest in a variety of disorders affecting attentional processes; this multi-component structure possibly would account for some of the heterogeneity of the ADHD population and differences found between subtypes as currently defined. Posner and Petersen (1990) propose that three attentional networks comprise the whole system responsible for attentional processes. Posner (1990) suggests that one of the attentional networks (Vigilance network) may be the area of concern in individuals with ADHD. Rapport, Chung, Shore, Denney, & Isaacs, (2000) theorized that the deficits seen in children with ADHD result from a primary deficit in working memory and not inhibition.

Recently proposed theories of attention, executive function, inhibition, and working memory overlap and conceptualize the multiple constructs involved in ADHD with a variety of methodologies (Pennington, Bennetto, McAleer, & Roberts, 1996). These competing theories offer potential insight into difficulties experienced by children with ADHD. The identification of core or primary deficits and greater understanding of the interplay of processes involved in ADHD can aid clinicians, teachers, and parents in working with children with ADHD.

Statement of the Problem

Advancements in theory, technology, and psychometric properties of psychological and neuropsychological measures may lead to a greater understanding of ADHD. New and improved technology can reveal neurobiological and genetic information underlying ADHD; at the same time, we can begin to triangulate the available knowledge of the processes and deficits accounted for by ADHD. Improved assessment measures also provide a means for testing the various conceptual and theoretical models now being proposed. Recent studies have examined the clinical utility and validity of neuropsychological measures often used to diagnose executive dysfunction and ADHD (Grodzinsky, & Barkley, 1999; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Perugini, Harvey, Lovejoy, Sandstrom, & Webb, 2000; Rapport et al., 2000).

Several researchers have investigated the use of combinations of tests and test scores in order to increase diagnostic sensitivity and specificity (Doyle, Biederman, Seidman Weber, & Faraone, 2000;Grodzinsky, & Barkley, 1999; Perugini et al., 2000; Rapport et al., 2000). Given the heterogeneous behavioral manifestation of ADHD, no single assessment tool or test score can adequately reflect the myriad of ADHD symptoms or distinguish it from other disorders (Doyle et al., 2000). In a recent review of literature on ADHD, Sergeant, Geurts, and Oosterlaan (2002) found that few studies examined differences between children and youth with ADHD and other clinical groups. The authors suggested that the lack of comparison to children with other clinical diagnoses limits our current understanding of the executive processes involved.

Comparing children with ADHD to children with other diagnoses that also have potential effects on executive functions can aid differential diagnoses between disorders.

Despite recent improvements in assessment procedures, measurement issues abound because researchers attribute differing processes when assessing the behavioral manifestations of ADHD despite using the same tools. This complicates the identification of the primary deficits associated with a given disorder. Thus, without continued research in order to establish construct validation of measures frequently used to assess children and youth with ADHD, it will be difficult to determine the primary deficits of ADHD.

When considering the current theories and neurobiological evidence, further investigation into the interplay and underlying deficits of children and adolescents with ADHD is needed. Therefore, this study examined the interplay of measures of inhibition, attention, working memory, and planning in children and adolescents. To facilitate the investigation of the differential contribution of inhibition, working memory and planning/problem solving in executive function deficits in children with ADHD, measures were initially selected based on factor analytic studies and theoretical conceptualizations. These were then evaluated using latent variable analyses.

As conceptualized and described in current theories of attention, planning, inhibition, and working memory, difficulties with these mental processes interact to manifest the behavioral syndrome(s) of ADHD. Therefore, given the neurological and psychological literature, it was predicted children and youth with ADHD will perform poorer on measures of inhibition, attention, working memory, and planning than children with no diagnoses. Further, children and adolescents with ADHD were expected to differ from participants with other (non-ADHD) clinical diagnoses such that children with ADHD demonstrate greater executive dysfunction in one or more areas of working memory, attention, inhibition, and planning abilities. Finally, the domains of inhibition, working memory, planning and attention were examined in order to determine which domain accounted for more differences between groups.

Research Questions

Specific research questions addressed were:

1) *Did children and adolescents with ADHD (Combined Type and Predominantly Inattentive Type) differ from normal controls on measures of inhibition, attention, planning, and working memory?*

2) *Did children and adolescents with ADHD (Combined Type and Predominantly Inattentive Type) differ from children with Other Clinical (non-ADHD) diagnoses on measures of inhibition, attention, planning, and working memory?*

3) *Which domain score accounted for more between group variance (ADHD, clinical control, and normal control or CT, PI)?*

Definition of Terms

Some of major terms used in this study are briefly defined. The terms ADHD, executive function, attention, inhibition, planning, and working memory are presented. They are discussed in further in detail in Chapter II.

ADHD is defined by behavioral symptoms that are outlined in the DSM-IV-TR (see Appendix A; APA, 2000). In summary, ADHD is a persistent pattern of inattention and/or hyperactivity-impulsivity that occurs more frequently and with greater intensity than is observed in typical individuals of a comparable developmental level (APA, 2000).

Executive function is a multi-component construct or umbrella term including a variety of behaviors such as planning, organization, self-regulation, problem-solving, abstract reasoning, strategy use, and goal directed behavior, as well as others (Lee, Romine, Wolfe, & Wong, 2002). Butterfield and Belmont (1977) operationally defined executive functions as when "a subject spontaneously changes a control process or sequence of control processes as a reasonable response to an objective change in an information processing task" (p. 284).

Attention is a multi-dimensional set of processes that can be divided into a number of distinct functions, including focus-execute, sustain, encode, and shift (Mirsky, 1996). However, for this study, attention was closely related to the neuropsychological term of vigilance and was defined as the ability to sustain and maintain attention (Nigg, 2001).

Inhibition is frequently defined as withholding a prepotent response and that definition was used in this study. The definition of planning selected was defined by Culbertson & Zillmer (1998b); it "involves the delineation, organization, and integration of behaviors needed to operationalize an intent or achieve a goal" (p. 285). Pennington (1994) defined working memory as the "computational arena, in which information relevant to the current task is both maintained on-line and subjected to further processing" (p. 21).

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CHAPTER II

REVIEW OF LITERATURE

Attention Deficit Hyperactivity Disorder (ADHD) is a widely known disorder and often referred to in the popular media. When conducting a search of the Internet using a popular search engine (www.google.com), there were 874,000 hits for “ADHD”. One website (WebMD) was recently featured on the television news. Newscasters joked about having ADHD after completing a checklist of behavioral symptoms of ADHD on the web site. They remarked that everyone must have ADHD. While the site clearly reads, “An accurate diagnosis can only be made through a clinical evaluation”, the commentators were amused with the six-question checklist and the frequency at which individuals must be diagnosed with ADHD (World Health Organization [WHO], 2003). It is this lack of understanding about the differences between commonly experienced inattention and distractibility as compared to the clinical level of symptoms and deficits experience by individuals with ADHD that contribute to some of the controversy surrounding the disorder. While clinicians are more likely to have training regarding the intensity, frequency, and durations of symptoms needed to consider a diagnosis of ADHD, difficulties with misdiagnoses are still a strong concern. Across the country, there are vast differences in the methods that professionals use to diagnosis ADHD in children. For example, children attending Texas public schools must be diagnosed by a physician in order to receive services for difficulties with ADHD under Other Health Impaired. In Virginia, psychologists can diagnosis a child with ADHD by obtaining information regarding the child’s functioning from the teacher, parents, and by direct observations. Although there is a great deal of publicity surrounding the disorder, the need to better understand the neuropsychological and neurobiological correlates of ADHD is evident given the relatively high prevalence.

ADHD is characterized by symptoms of inattention, hyperactivity, and impulsivity. The DSM-IV-TR includes four possible diagnoses of ADHD: predominantly inattentive type, predominantly hyperactive/impulsive type, combined type, and not otherwise specified type (see Appendix A; APA, 2000). Diagnosis is based on behavioral criteria and a designated number of symptoms that must be experienced in individuals before the age seven years, in two or more settings and cause significant problems in social, academic, or occupational areas. Given the overlap of behaviors associated with ADHD and other disorders, the symptoms experienced must not be better explained by other clinical disorders. If adolescents and adults no longer meet criteria yet some symptoms persist, they can be considered "in partial remission" (APA, 2000). Many of these criteria, including age of onset are not universally supported (e.g. Barkley & Biederman, 1997). For example during the DSM-IV field trials, data collected suggested that many children do no exhibit clinically significant symptoms until older ages when demands are increased (i.e. school work becomes difficult; Rowland, Lesesne & Abramowitz, 2002).

Another aspect of the current ADHD criteria that is under investigation is the use and validity of the subtypes. Lahey et al. (1998) found that during the field trials of the DSM IV, only 24% of children diagnosed with the hyperactive-impulsive type were over the age of six years. In general, the hyperactive type occurs less often and the type is identified more often in young children (Hart et al., 1995). Marsh and Williams (2004) examined subtypes finding support for the Combined Type and the Predominantly Inattentive Type but not for the Hyperactivity-Impulsivity Type. It is thought that the hyperactive type diagnosis may be a precursor to the combined type (Barkley, 1997).

ADHD affects 4%-5% of children (APA, 2000; Barkley, 1998). Boys are more frequently diagnosed at a rate of 3:1 to 9:1 (APA, 2000). Given that research is primarily based on referred samples, more is known about ADHD in boys than in girls. When prevalence rates are considered, boys are referred more often than girls. In community-based samples the male to female ratio is 3:1; however, in clinically-based samples the ratio increases to 9:1 (APA, 1994). The gender difference may reflect a referral bias because boys can display or be perceived as more disruptive than girls as well as a true gender difference (Breen & Altepeter, 1990; Rowland et al., 2002).

Adolescents continue to have the same neuropsychological deficits that are present in children (e.g. Fischer, Barkley, Edlebrock, & Smallish, 1990). Of those children diagnosed with ADHD, 30% -70% will continue to be affected by the disorder into adulthood (e.g. Barkley et al., 1990). Symptom presentation may be related to age with symptoms remitting as an individual matures; although, some individuals may continue to display symptoms even though they no longer meet the criteria for a diagnosis (Biederman et al., 2000). No prevalence or base rate has been established for adults with ADHD; however, studies have estimated that between 0.30% and 3.5% of the adult population have ADHD (Barkley, 1998; Heiligenstein, Guenter, Levy, Savino, & Fulwiler, 1999). Although, individuals may no longer meet the criteria for ADHD, children previously diagnosed had lower educational attainment, lower occupational status, and a greater likelihood of experiencing antisocial personality disorder and/or substance abuse (Mannuzza, Klein, Bessler, & Malloy, 1993). These adults no longer meeting the criteria for ADHD appeared to continue to have consequences of executive dysfunction. The interest in adults with ADHD is growing. It has been hypothesized that the interaction of development and the ADHD symptomology results in changes in symptom sequelae and that the diagnostic criteria that were based on child studies may not be appropriate for adults (NIH, 2000).

Comorbidities are associated with all subtypes of ADHD; however, specific problems more often are associated with certain subtypes. Researchers have found individuals with the inattentive type to have a greater co-occurrence of learning problems, anxiety, depression, and to receive more help in school (Faraone et al., 1998). In contrast, children and adolescents with the combined type evidence a greater incidence of behavior and conduct problems, poor family, and peer relations, early substance use; they are referred more frequently for psychological intervention (Faraone et al., 1998; Gaub & Carlson, 1997). For those individual with the combined type, Oppositional Defiant Disorder and Conduct Disorder comorbidity rates are thought to be as high as 40% to 65% (Barkley, 1990). ADHD has frequent comorbidity rates with Tourette Syndrome (25%-80%), affective disorders (15%-75%), anxiety (25%) and sleep disorders (30%-40%; Comings, 2001). Other problems such as alcoholism and substance use range for 5% to 20% (Comings, 2001).

To date, there is no widely accepted theory of ADHD. The variety of symptoms and behaviors exhibited by children and adolescents with ADHD has led to research into different etiologies, development, and neurobiological findings among subtypes. Researchers have explored the symptoms and defined characteristics of ADHD from neuroanatomical, neurochemical, neuropsychological, and cognitive perspectives. The recently proposed theories of attention, executive function, inhibition, and working memory that conceptualize the multiple constructs involved in ADHD from a variety of methodologies need to be further investigated (Pennington et al., 1996).

Historical Perspective of ADHD

One of the first clinical references to the behavioral characteristics associated with ADHD in children was by an English physician George Still in 1902 (as cited in Hassler, 1992: Mash & Barkley, 1996; Spencer, 2002). In a presentation to the Royal Academy of Physicians, Dr. Still described 20 children from his practice who exhibited symptoms associated with what is now called ADHD (Mash & Barkley, 1996). Interestingly, Dr. Still's sample was comprised of three times as many males as females, and had family histories of excessive alcohol use, depression, oppositional and criminal conduct. Dr. Still also considered the possibility that these behaviors could be a result of injury or insult. Over a hundred years later, these characteristics are still associated with the behavioral syndrome of ADHD.

Approximately 15 to 20 years later, similar behavioral observations were associated with children who had experienced head trauma or encephalitis (Mash & Barkley, 1996; Spencer, 2002). As early as 1938, Levin found an association with children who exhibited excessive restlessness and brain lesions in the frontal lobes (as cited in Spencer, 2002). These observations of children were consistent with earlier literature from 1876 which described primates with frontal lobes lesions as being "restless and purposeless" in their behavior (as cited in Spencer, 2002, p. 315). The association of trauma, lesions, and encephalitis with inattention, impulsivity, and hyperactivity led clinicians to hypothesize that the behavioral symptoms were manifested because of minimal brain dysfunction (Mash & Barkley, 1996).

In the 1950's and 1960's, clinicians began to describe and label children as hyperkinetic (as cited in Mash & Barkley, 1996). ADHD was thought to have excessive motor movement as the primary deficit (APA, 1968). The disorder first appeared in the *Diagnostic and Statistical Manual of Mental Disorders-Second Edition* (DSM-II) as the "hyperkinetic reaction of childhood" (APA, 1968). The entry read "This disorder is characterized by overactivity, restlessness, distractibility, and short attention span, especially in young children; the behavior usually diminishes in adolescence. If this behavior is caused by organic brain damage, it should be diagnosed under the appropriate non-psychotic organic brain syndrome" (APA, 1968; p. 50). During this time, the psychoanalytic perspective shaped the definition of the disorder as a reaction of children to environmental and family factors (Mash & Barkley, 1996).

The disorder next was defined by the lack of attention and impulse control (APA, 1980) with a change in the name of the disorder to Attention Deficit Disorder (ADD). The DSM III distinguished two types, ADD with hyperactivity and ADD without hyperactivity (APA, 1980). The current terminology of ADHD was introduced in the DSM-III-R (APA, 1987). Under these criteria, subtypes were no longer identified and the focus again shifted to the hyperactivity. The DSM-IV returned to distinguishing subtypes of ADHD; however, some prominent researchers are calling for yet another definition of the primary deficits in ADHD (e.g., Barkley, 1997, 1998).

Frontal Lobe Dysfunction

Historically, from a neuropsychological perspective, executive function also has been associated with the frontal lobes. Denckla (1996) suggested that although executive function may be located in the frontal lobes, the frontal lobes perform more than executive function. At the same time, although the neural substrates of executive function consistently have been associated with the frontal lobes recently there is some evidence that not only the frontal lobes are involved in executive tasks (Stuss & Knight 2002). The prefrontal cortex has reciprocal connections to the basal ganglia, the limbic system, the thalamus, and the posterior cortex (Pennington et al., 1996).

Posner (2002) suggested that the ability to converge psychological and biological development is approaching. He indicates that with recent advancements and the use of new technology with children, in particular, that our ability to learn more about etiology of disorders and development in general are increasing. Functional magnetic resonance imaging (fMRI) studies indicate that inhibitory and working memory processes activate the dorsolateral area of the prefrontal cortex (Stuss & Knight, 2002); however, neural networks involved with ADHD are not confined to the pre-frontal or frontal cortex. Studies have implicated the basal ganglia and cerebellum (Castellanos, Giedd, Marsh, & Hamburger, 1996; Gottwald, Mihajlovic, Wilde, & Mehdorn, 2003; Semrud-Clikeman et al., 2000). Volume differences have been found between children with ADHD and controls in the cerebellar vermis (Berquin et al., 1998; Castellanos et al., 2001; Mostofsky, Reiss, Lockhart, and Denckla, 1998) and the caudate in the basal ganglia (Castellanos et al., 1996; Filipek et al., 1997; Semrud-Clikeman et al., 2000).

Early conceptualizations of ADHD were related to impaired “frontal” functions. As noted earlier, following World War I an epidemic of encephalitis resulted in children with abnormal behaviors such as hyperactivity, impulsivity, and antisocial behavior (Hassler, 1992). Similar behaviors also were noted for children with frontal head injuries and lesions (Spencer, 2002). Frontal lobe pathology did not result in primary impairments of sensory, motor, language, and memory abilities (Zillmer & Spiers, 2001). The overlap in symptoms and similarity to ADHD initially led researchers and clinicians to associate frontal lobe dysfunction with ADHD. Frontal lobe deficits were reconceptualized as executive function deficits in children with ADHD and other disorders.

Executive Function

Overall, research has indicated a variety of problems associated with ADHD. Youth with ADHD experience difficulties with executive functions (Culbertson & Zillmer, 1998a; Pennington, 1997) and perform poorer on frontal lobe tasks (Tripp, Ryan, & Peace, 2002). Some executive difficulties experienced by youth with ADHD include poor organization, problem solving, planning, and social skills, as well as low self-esteem, low frustration tolerance and impaired academic performance (e.g.

Ackerman, Anhalt, Holcomb, & Dykman, 1986; Voleker, Carter, Sprague, Gdowski, & Lachar, 1989).

A meta-analytic study found that children with ADHD showed significant impairment on most executive function measures (Pennington & Ozonoff, 1996); however, many researchers have found that some measures of executive functions are more sensitive to ADHD than others are (Shallice et al., 2002). Specifically, children with ADHD performed poorer on measures of attention span, sustained attention, inhibition, and working memory and parent ratings indicating higher levels of inattention or hyperactivity were associated with worse performance on neuropsychological measures (Muir-Broaddus, Rosenstein, Medina, & Soderberg, 2002). Many of these problems are related to or fall under the umbrella of executive dysfunction.

Executive function is a multi-component construct or umbrella term including a variety of behaviors such as planning, mental flexibility, attentional allocation, working memory, and inhibitory control (Zillmer & Spiers, 2001). Sergeant et al. (2002) in a review of executive function research with children with ADHD, found 33 definitions of executive functions. Several researchers include inhibition and working memory under the domain of executive functions (Denckla, 1996; Miyake et al., 2000; Pennington, 1994) but others do not. Despite many definitions of executive function, there are some common features in most definitions. For example, most definitions include planning or future directed/oriented behavior as a component of executive function (Denckla, 1996).

Of these executive functions, when considering children with ADHD, specific researchers have proposed impaired inhibition as the underlying deficit affecting executive function processes (Barkley, 1997; Quay, 1997). Barkley (1997) proposed disinhibition as the primary deficit of ADHD; disinhibition then contributes to difficulties in working memory and executive functions. In contrast, Pennington (1994) and Rapport, Chung, Shore, & Isaacs, (2001) argued for working memory as being primary and contributing to deficits in executive function and inhibition processes. Mirsky (1987) proposed a four factor model of attention such that children and adolescents with ADHD have deficits in three out of the four factors. Fernandez-Duque and Posner (2001) proposed that attention is comprised of three systems; Orienting Attentional System, Executive Attentional System, and Vigilance Attentional System. Of these, Posner proposed that ADHD is a disruption of the Vigilance Attentional System (1990).

Inhibition

Inhibition is considered by many to be one component under the umbrella term of executive function. Failure to inhibit (or disinhibition) in children might result in behaviors such as "responding before the task is understood, answering before sufficient information is available, allowing attention to be captured by irrelevant stimuli (i.e. distractibility) or failing to correct obviously inappropriate responses" (Schachar & Logan, 1990, p. 710). This conceptualization of disinhibition covers a broad spectrum of behaviors frequently seen in young children as well as those diagnosed with ADHD. There are, however, multiple of definitions of inhibition; Sergeant et al. (2002) found 12 definitions in their review. Inhibition is often defined as withholding a prepotent response. Lack of inhibition, or disinhibition, is closely related to attention and impulsivity.

When considering development and the ability to selectively attend or inhibit, children improve with age, including those children with ADHD. However, children with ADHD continue to lag behind children without ADHD in the development of inhibition (Brodeur & Pond, 2001). Schachar and Logan (1990) examined differences in both children and adults on an inhibition task (i.e., stop task). Findings indicated normal inhibition is well developed early on with children evidencing a similar rate of errors as adults by the second grade. However, younger children had more variability in their responding rates and slower response times overall than did either older children or adults. When contrasting the ADHD group to normal controls, the ADHD group inhibited fewer responses than did the normal controls; differences between the children with ADHD and those with other clinical diagnoses were not significant suggesting the stop task may lack specificity.

As noted earlier, several authors have proposed disinhibition as the possible underlying process impacting or manifesting as deficits in working memory and executive function in individuals with ADHD (Barkley, 1997; Borkowski, & Burke, 1996; Denckla, 1996). Barkley's unified theory of ADHD (Barkley, 1997) posited behavioral disinhibition as the primary deficit for ADHD Combined Type that leads to of the secondary deficits often associated with ADHD Combined Type.

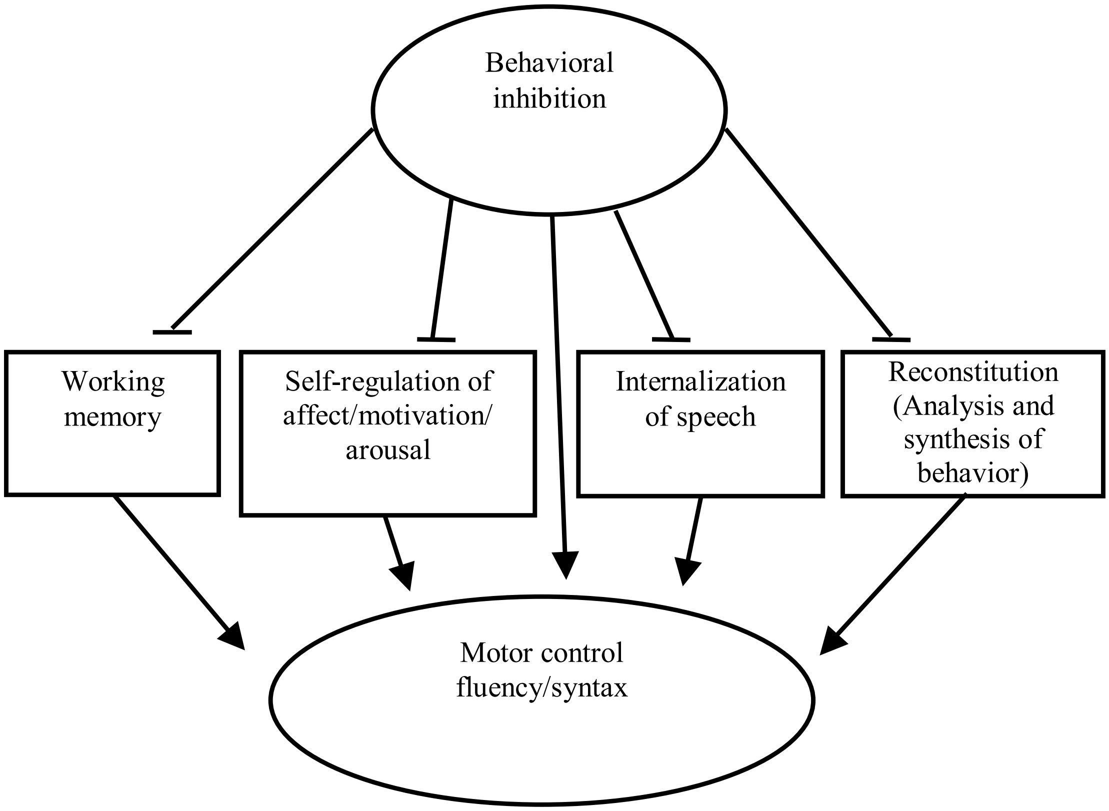

Figure 1 Summary of Barkley's Model of ADHD (1997)

Barkley's theory suggested that behavioral inhibition "permits the proficient performance of four executive abilities: working memory, internalization of speech, self-regulation of affect-motivation, arousal, and reconstitution" (p. 72; see Figure 1). These executive functions are secondary to behavioral inhibition as described by Barkley. Notably, Barkley asserted that attentional problems associated with ADHD-Predominantly Inattentive type are qualitatively different from and arise from different mechanisms than the deficits associated with the Combined Type. As such, attention is not included as a component in Barkley's model.

Barkley's conceptualization of inhibition refers to three interrelated processes. The process involves "(a) inhibition of the initial prepotent response to an event, (b) stopping of an ongoing responses, which thereby permits a delay in the decision to respond; and (c) the protection of this period of delay and the self-directed response that occurs within it from disruption by competing events and responses (interference control)" (p. 67). Inhibition, in Barkley's model of ADHD, is the primary deficit, which contributes to difficulties with other executive processes that are "downline" (see Figure 1.)

According to Barkley, ADHD affects executive functions because the first act of self-regulation must be the inhibition of responses (Barkley, 1990). The four executive functions in the model; working memory, self-regulation, internalization of speech and reconstitution are considered separate neuropsychological systems secondary to the inhibition system. In this model of ADHD, working memory and planning are impacted by the child's inability to inhibit. Therefore, measures of inhibition should account for more variance in performance of children with ADHD on executive function measures. Other components of executive functions such as working memory, planning, and attention, should account for less of the observed differences on executive function measures. Barkley makes a distinction that the executive processes he included in this model do not have a causal relationship with inhibition; however, inhibition needs to occur to allow working memory, self-regulation, internalization of speech and reconstitution to occur. Others perceive the relation between inhibition and working memory differently.

Working Memory

Working memory (WM) has been conceptualized in a myriad of ways and measured using multiple methodologies. Working memory was defined by Pennington (1994) as part of a system that is a "computational arena, in which information relevant to the current task is both maintained on-line and subjected to further processing" (p. 21). It is the future orientation of working memory that differentiates it from short-term memory. Although short-term memory holds information in the conscious awareness, it is not future oriented (Pennington, 1994).

Since there has been little empirical or theoretical research of the relation among executive function, working memory, and attention (Pennington et al., 1996), there is a more recent trend to examine the role of working memory in individuals with ADHD and other disorders. Pennington et al. (1996) suggested that working memory deficits may be the primary deficits underlying executive function deficits. Their model further asserted that inhibition is a separate cognitive process, but related to working memory. Cohen and Servan-Schreiber (1992) also suggested that tasks thought to tap prefrontal functioning are two-dimensional such that individuals will display executive function dysfunction if both working memory and inhibition are required, *or* if very high demands are placed on one or the other. However, Pennington (1994) conceptualized working memory as maintaining information as well as inhibiting information. Since Pennington includes inhibition as a component of working memory, it would follow that impairments in inhibition would impact working memory.

Baddeley and Hitch (1974) proposed a model of working memory. As researchers have hypothesized and investigated working memory deficits in children with ADHD, Baddeley's model has been considered. Baddeley and Hitch (1974) proposed a three part model of working memory. The model included the phonological loop, the visuospatial sketchpad and the central executive. The phonological loop and visuospatial sketch pad are temporary buffers. The phonological loop involves a "phonological or acoustic store" that lasts for approximately 2 seconds unless the store is refreshed or maintained by subvocal rehearsal (Baddeley & Hitch, 1994; p. 486). The visuospatial sketch pad holds spatial information in mind temporarily. The central executive coordinates the activities between the buffers and controls attention. Twenty years after originally proposing the model, Baddeley and Hitch, wrote that the central executive "is the most complex and least well understood component of working memory" (1994; p. 490).

The role of central executive in coordinating the buffers is greatly expanded and is thought to have attentional control and be involved in the switching of plans (Baddeley & Hitch, 1994). A recent study investigated Baddeley's model of working memory with children with ADHD (Karatekin, 2004). Karatekin found that children with ADHD did exhibit impairments in working memory and they used rehearsal methods as effectively as normal controls. However in the sample of children studied, those with ADHD performed poorer on measures thought to tap the central executive or divided attention.

The central executive in Baddeley's model is described as attentional control or involved in switching of plans. The overlap or difficulty of defining or delineating the different components of executive functions becomes apparent. Further research is needed to understand the relationship of attention, planning and problem-solving and working memory.

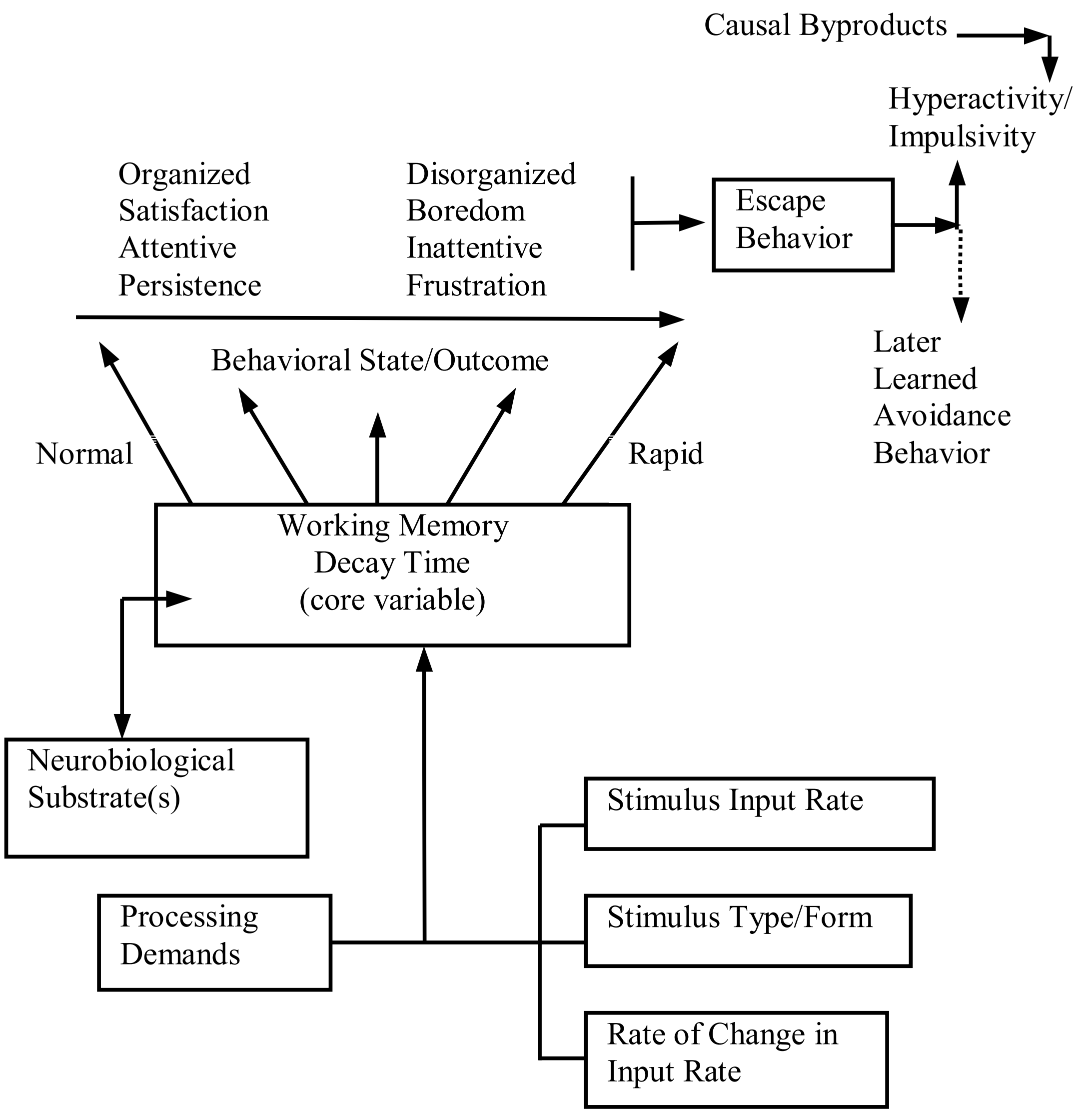

Figure 2 Rapport's Model of ADHD (2001)

Rapport et al. (2001) proposed that the core or primary deficit in ADHD is working memory. In their theory, working memory is defined as the processes that construct, maintain, and manipulate information. It is working memory processes that allow for organized, future-oriented behavior or problem-solving skills. In fact, organized responses or behaviors are dependent upon working memory processes and difficulties with working memory skills result in disorganization, boredom, inattention, and frustration (see Figure 2). The break down of working memory causes children to have stimulation seeking behaviors. These behaviors (hyperactivity and impulsivity) fill or replace the rapidly fading working memory traces. The quick fading working memory processes cause children with ADHD to seek rapid input of information to fill the void. In this model, attention is described as the target of working memory. Inattention does not exist in that; there is always conscious activity. In this model, children with ADHD learn to avoid the type of tasks that place demands on working memory processes using escape behaviors to avoid the aversive tasks (Rapport et al., 2001). Rapport et al., (2001) concluded that disinhibition or the inability to appropriately inhibit responses is a product of working memory processes.

Similar to the inhibition theories that hypothesize disinhibition as a primary deficit, theories suggesting that working memory deficits account for executive dysfunction are testable. However, as noted earlier there is a great deal of overlap in the conceptualizations of the theories proposed. In addition, there may difficulty in determining which assessment tools most cleanly measure executive function, specifically, inhibition, working memory, planning, and attention.

Planning/Problem Solving

Culbertson and Zillmer (1998b) defined planning as "involving the delineation, organization, and integration of behaviors needed to operationalize an intent or achieve a goal" (p. 285). Luria (1973) wrote, "the role of the prefrontal cortex is the synthesis of systems of stimuli and the creation of a plan of action is manifested not only in relation to currently acting stimuli, but also in the formation of active behavior directed toward the future" (p. 91). Abilities to plan and problem solve are critical in every day life; injuries or disorders impacting children in the prefrontal lobes and subcortical regions have been found to significantly interfere with a child's ability to obtain those skills (Eslinger, Biddle, & Grattan, 1997). One of the most common types of measures used to tap planning abilities is a tower task. In five out of seven studies, children with ADHD have displayed more difficulty when solving tower tasks as compared to normal controls (Sergeant et al., 2002).

There is a variety of tower tasks available and researchers frequently adapt those tasks to their purposes. With the increased importance placed on the psychometric properties of assessment tools, the need for a standardized and normed planning task is evident. In order to measure planning skills, Shallice (1982) devised the first Tower of London (TOL). Shallice developed the original TOL because the Tower of Hanoi (TOH) did not allow for the presentation of multiple problems at the same level of difficulty (Culbertson & Zillmer, 1998b). Culbertson and Zillmer recently revised the TOL to provide better standardization and improved normative data.

Welsh, Satterlee-Cartmell, and Stine (1999) compared the Towers of Hanoi. In the sample of normal adults, 84% of the variance in scores was not shared variance. Further, findings indicated that performance on working memory and inhibition tasks explained just over half the variance in TOL scores but not TOH performance. Although this study provides useful information regarding the performances on the TOL, the authors only investigated the TOL total score and did not investigate planning's role in TOL performance. It is not known whether the different scores (i.e., initiation time and total moves) would tap inhibition, planning and/or working memory. These validity studies exemplify of some of the problems in interpretation, research, and validation of neuropsychological measures. Differences in administration materials (i.e. computer vs. hand administration, number of balls or discs used), differences in scoring procedures (inclusion of initiation time), and use of small samples, make interpretation of these studies difficult (Baker, Segalowitz, & Ferlisi, 2001). Sergeant et al. (2002), after completing a comprehensive review of neuropsychological measures frequently used to assess children for attention problems, discussed the need for future research to determine the clinical usefulness of tower tasks in differentiating clinical groups as well as normal controls.

Attention

Since 1873, psychology has investigated and theorized about the processes, mechanisms, and development of attention (Luria, 1973). Initial debate concerned the existence of attention outside of perception. Similar to Descartes statement "I think therefore I am" some theorists proposed, "I perceive, therefore I attend" while others, suggested attention is a "manifestation of a specific mental factor" that is distinct from perception (Luria, 1973, p. 257). At some level, this debate continues with the investigation of localized attention and inhibition processes.

Attention is comprised of involuntary and voluntary components (Luria, 1973). Luria defined attention as the "*directivity and selectivity of mental processes*" (p. 257). He described an elementary level of attention as "orienting" behaviors, which can be observed in the first few weeks of life, such as an infant orienting to a novel visual stimulus or sound. Luria proposed a process of development in which attention becomes "*highly selective* in character, thus creating the basis for directive and selective, organized behavior" as the individual matures (p. 259). When examining research literature, Luria suggested that attention at its most basic level (arousal) is mediated by the reticular activating system. When considering evoked potential research available at the time, the selective recognition of a stimulus and the inhibition of responses for irrelevant stimuli were viewed as organized by the frontal lobes and the limbic cortex (hippocampus and amygdale). Luria considered these processes to be higher order attentional processes. Some thirty years later researchers are still investigating these areas of the brain and their relationship to attentional processes with newer technology. Theories continue to be refined and revised based upon research in behavioral and neuroanatomical processes.

Posner (1992) proposed a theory of attention including anterior, posterior, vigilance attentional systems. The theory was based on available research with animals and advancements in imaging technology using PET scans. Attention is defined as 1) orienting to sensory events, 2) detecting signals for processing and 3) maintaining vigilance or an alert state (Posner & Petersen, 1990). In 2001, Fernandez-Duque and Posner revised the model of attention that was previously proposed. The model retained three attentional networks; the orienting network, the vigilance network, and the executive network. Posner and Petersen (1990) describe several attributes of attention important in the model and these apply to the updated model (Fernandez-Duque & Posner, 2001). First, attention is a system that is interrelated with other processes or systems in the brain but also a distinct system. Second, that attention is carried out by an anatomical network and not by a single area or by the brain as a whole. Lastly, those different areas in the brain carry out different processes or functions of the attentional system.

Posner's model of attention suggests that the anterior portion detects "signals for conscious processing" and the posterior region of the brain orients attention (Posner & Peterson, 1990, p. 27). The anterior system is involved in attending to the meaning of what is seen or heard and appears to be important in regulation. The anterior network that Posner proposed includes the prefrontal cortex, the anterior cingulate and the basal ganglia (Posner & Dehaene, 1994).

The posterior attention network is comprised of the parietal cortex, pulvinar, and superior colliculus (Posner, 1992). Posner hypothesized that the parietal lobe disengages attention from its focus, the midbrain acts to move attention to the new area or shift attention, and the pulivinar (in the thalamus) is involved in focusing on the new area of attention or holding and maintaining the attention in place. Posner (1992) suggested that damage to the alerting network or the vigilance attentional system may manifest in the difficulties experienced by children with ADHD. Further, at a neurochemical level, Posner suggested norepinephrine may be involved in ADHD, particularly in relation to right frontal lobe function.

Recently the model of attentional networks was revised to include an executive network in addition to the vigilance network and orienting network (Fernandez-Duque & Posner, 2001). The orienting network refers to the network that is involved in "the selection of sensory information" (Fernandez-Duque & Posner, 2001; p. 75). PET and fMRI studies indicate that the anatomical network involved in orienting is the precentral gyrus of the frontal lobe and areas located in the parietal lobe.

Vigilance is defined as "the ability to achieve and sustain the alert state" (Fernandez-Duque & Posner, 2001; p. 82). Continuous performance tests are one of the tasks that are often used to study vigilance. Posner and Petersen (1990) suggested that vigilance may be in the right hemisphere. Several studies have found activation in the right frontal-parietal system when subjects are in a vigilant state for both visual and auditory tasks (e.g. Cohen, Semple, Gross, & Holcomb, 1988; Pardo, Fox, & Raiche, 1991) as well as smaller right-side anatomical structures in ADHD subjects (Casey et al., 1997; Castellanos et al., 1996; Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopulos, 1990). These more recent MRI studies (Casey et al., 1997; Castellanos et al., 1996; Hynd et al., 1990) support the right prefrontal-striatal-cortical dysfunction theory that was suggested by Posner and Peterson (1990) as the possible area of deficit in children with ADHD.

Interestingly, the most significant change to Posner's original theory was the addition of an executive network. Executive attention involves "effortful control or coordination", inhibitory control, self-monitoring, and "participates in planning" (Fernandez-Duque & Posner, 2001; p. 85). The anatomical correlates for executive attention include the anterior cingulate, orbitofrontal cortex, dorsolateral prefrontal cortex, basal ganglia and areas of the thalamus. Fernandez-Duque and Posner (2001) suggest that executive function deficits from failure to inhibit may be secondary to a vigilance deficit or that the processes interact.

Mirsky, Pascualvaca, Duncan, and French (1999) proposed a neuropsychological model of attention and examined its relationships to ADHD. Their model of attention was originally derived from factor analytic methods. In Mirsky et al.'s model, attention is comprised of the abilities to focus/execute, sustain, encode, and shift. As with Posner and Peterson's model (1990), Mirsky et al., (1999) conceptualizes attention as a multi-component system with each function in the system being supported by different areas of the brain. However, the system acts as a whole and specialization is not absolute allowing for one function to substitute for others in the case of injury or disorder. The ability to focus, as conceptualized in Mirsky's model, is located in the superior temporal cortex, the inferior parietal cortex, and the corpus striatum. Sustaining attention occurs in the mesopontine reticular formation and the reticular thalamic nuclei. The dorsolateral prefrontal cortex and the anterior cingulated gyrus supports shifting attention. The ability to encode information is supported by the limbic system, hippocampus and the amygdala.

Mirsky et al. (1999) suggested that their attention battery "should be a part of every neuropsychological evaluation" to assess the components of attention that may be compromised in a particular disorder (p. 172). Preliminary investigations found that children with ADHD were impaired on three of the four components as defined and measured by Mirsky; these were focus, shift and sustain (Mirsky et al., 1999). The children with ADHD also had poorer performance than controls on one of two measures used for encoding; they demonstrated difficulties on Digit Span but not with the Arithmetic subtest on the Wechsler Intelligence Scale for Children (WISC-R; Wechsler, 1991). Mirsky described these measures as capturing encoding processes; however, they are often used as measures of working memory. Other researchers have proposed that the deficits exhibited in children with ADHD are result of working memory deficits (Pennnington, 1994; Rapport et al., 2000). The overlap in conceptualization of constructs by researchers adds to the difficulty of interpreting results from studies. While the encode component of attention overlaps with working memory, inhibition is subsumed by the focus component of the attention model. Children with ADHD demonstrated difficulties with “the capacity to focus on a task in the presence of distraction” as measured by Trails B (Reitan, 1992) and Stroop Word (Golden, 1978) performances (Mirsky et al., 1999, p. 173).

Developmental Perspective of ADHD

Whenever one assesses children and adolescents, the interaction of development with observed behaviors should be considered. Traditionally, neuropsychological measures have been used and developed with adults in mind (Welsh & Pennington, 1988). The development of executive function is thought to follow a trajectory parallel to the development of the frontal lobes. Diamond and Goldman-Rakic (1986) reviewed a series of studies finding evidence to support the early development of executive function and inhibition in infants as young as one year of age. Luria (1973) suggested the frontal lobes, included in his third functional unit of the brain, reach maturity by age 4 to 7 years.

Investigations that are more recent indicated continued frontal lobe development at least through age 12 years (Welsh, Pennington, & Grossier, 1991). Imaging studies suggest continual frontal lobe development into adulthood (Pribram, 1997). Using a newly developed battery designed and normed for use with children and adolescents, results indicated inhibition, attention, and executive function, although highly related, had differing rates of development (Klenberg, Korkman, & Lahti-Nuuttila, 2001). In a large normative sample of children, it was found that children first developed inhibition (by age 6 years), followed by visual and auditory attention (at age 10 years), and finally, the children developed executive function as measured by the battery. Since the sample ranged from age 3-12 years, it is not known whether further executive function development would be indicated beyond age 12 years. Although it is difficult to generalize results from one measure to another, and more research is needed, this study by Klenberg and colleagues (2001) suggested that children with ADHD, who do not adequately develop inhibition, could demonstrate later difficulties with attention and executive function abilities, which are “downstream” or occur later in the developmental trajectory. The findings of Klenberg et al. (2001) also supported the need to examine executive function (i.e., planning, problem-solving, and strategy use) as separate from inhibition or attention.

This developmental trajectory follows the development of the anatomical structures thought to be involved in executive functions. The prefrontal cortex is not fully mature until mid-adolescence (Luciana & Nelson, 1998) with some studies suggesting continued development into early adulthood (Stuss & Knight, 2002.) The prefrontal cortex is thought to be involved in planning, working memory, strategy use and problem-solving skills (Stuss & Knight, 2002). Myelination in the prefrontal cortex is not complete until adolescence (Giedd et al., 1999). Both inhibition and working memory are thought to be associated with the dorsolateral prefrontal cortex, which undergoes developmental changes until early adulthood (Stuss & Knight, 2002).

Statement of the Problem

As researchers synthesize and integrate information from genetic, imaging, and neurochemical studies to develop comprehensive theories of ADHD, a great deal of research is generated. Examining and testing theories help further our knowledge about specific disorders, measurement of abilities, and increase our knowledge of brain-behavior relationships.

Neuropsychological measures provide a means to begin testing the theoretical conceptualizations of ADHD. Recent studies have examined the clinical utility and validity of neuropsychological measures often used to diagnose executive dysfunction and ADHD (Grodzinsky, & Barkley, 1999; Miyake et al., 2000; Perugini et al., 2000; Rapport et al., 2000). Given the multi-component nature of ADHD, no single assessment tool or test score can adequately reveal the myriad of ADHD symptoms or distinguish it from other disorders (Doyle et al., 2000). Several researchers have investigated the use of combinations of tests and test scores in order to increase diagnostic sensitivity and specificity (Doyle et al., 2000; Grodzinsky, & Barkley, 1999; Perugini et al., 2000; Rapport et al., 2000). For example, Rapport et al. reviewed 142 studies, published between 1980 and 1999, examining differences between children with ADHD and normal controls. These researchers reported several reliable differences between youth with ADHD and normal controls across measures. However, Sergeant et al. (2002) in a comprehensive review of literature on ADHD found that few studies examined differences between children and youth with ADHD and other clinical groups. The authors suggested this common methodical shortcoming limits our current understanding of these processes and their usefulness in differential diagnoses.

When considering the current theory and neurobiological evidence, further investigation into the interplay and underlying deficits of children and adolescents with ADHD is needed. The issue of correct diagnoses and improved understanding of the mental processes implicated in the disorders is needed in order to develop the most beneficial interventions. Uncovering and understanding the interplay of deficits in children with ADHD may lead to interventions that are more effective and provide better outcomes.

Purpose of the Study

The main purpose of this study was to examine the roles of inhibition, attention, working memory, and planning in children and adolescents with and without ADHD. As conceptualized and described in current theories of attention, planning, inhibition, and working memory, difficulties with these mental processes interact to manifest the behavioral syndrome(s) of ADHD. Therefore, this study examined differences in inhibition, attention, working memory, and planning in children and adolescents in order to examine the complex interplay among these constructs. To facilitate the investigation of the differential contribution of inhibition, working memory and planning/problem solving in executive function deficits in children with ADHD, measures were selected from factor analytic studies and latent variable analyses. Therefore, given the neurological and psychological literature, it was predicted children and youth with ADHD would perform poorer on measures of inhibition, attention, working memory, and planning than children with no diagnoses. Further, children and adolescents with ADHD were expected to differ from participants with other (non-ADHD) clinical diagnoses demonstrating greater executive dysfunction in one or more areas of working memory, inattention, disinhibition, and planning abilities. Finally, it was determined which component of executive functions selected for this study inhibition, working memory, attention or planning accounted for greater variance in the presence of ADHD. The method used for this study is described in Chapter III.

CHAPTER III

METHODOLOGY

The purpose of this study was to examine the interplay of inhibition, attention, working memory and planning as described in the various theories of ADHD. The rationale and underlying theory of this study were presented in Chapters I and II. In Chapter III, the methodology used is presented. Results and implications follow in Chapters IV and V.

Participants

Participants in this study were 93 children and adolescents (aged 9-15 years) who were consecutive referrals to the Memory, Attention, and Planning study (MAPS). Children were recruited through the use of flyers distributed in the local community to pediatricians, local schools, local support groups for individuals with ADHD, a community-based counseling center, posted on local bulletin boards and placed in the local newspaper. Participation was voluntary; parental consent and child assent were obtained. Parents or guardians of participants received a comprehensive report of the results following the completion of the evaluation. Exclusionary factors included low intelligence (IQ < than a standard score of 80), not speaking English, history of seizure disorder, history of traumatic brain injury warranting medical attention, or a previous diagnosis of schizophrenia or autism. Six individuals were excluded due to low cognitive functioning (Full Scale IQ < 80).

Of the participants who were included in the study (N=93), 74 (79.6%) were Caucasian, 11 (11.8%) were African-American, 7 (7.5%) were Hispanic, and 1 (1.1%)

was Asian; 63 (67.7%) were male and 30 (32.3%) were female. Most participants were right handed (n=82; 88.2%) with fewer left-handed participants (n=11; 11.8%). Of the 93 children included, 26 did not receive a diagnosis, 26 met criteria for a clinical diagnosis other than ADHD according to DSM-IV-TR and 41 met criteria for ADHD (2000). Diagnoses identified within the Other Clinical group included learning disabilities (reading n=2; math n=1;written expression n=1; learning disability NOS n=2), oppositional defiant disorder (n=1), dysthymia (n=2), generalized anxiety disorder (n=4), phobias (n=1), post-traumatic stress disorder (n=1), substance abuse (n=1), anxiety disorder NOS (n=1), depressive disorder NOS (n=2), adjustment disorder NOS (n=6), and schizoaffective disorder (n=1). Subtypes identified within the ADHD group included ADHD-NOS (n=1), ADHD-PI (n=13) and ADHD-CT (n=27). Based on two measures used for diagnostic decision-making and group placement, the participant with a diagnosis of ADHD-NOS was included with the PI group for the analyses. This participant had clinically significant difficulties with inattention as rated by the child's parent; however, the child was in the normal to at-risk range for hyperactivity on the Behavioral Assessment System for Children (Reynolds & Kamphaus, 1992). No ADHD-HI cases were identified in the sample; this is consistent with other studies. Demographic data by group are presented in Table 1.

Effects of Ethnicity, Gender, and Handedness

To determine if any differences existed between the four groups (ADHD-PI, ADHD-CT, Other Clinical, and No Diagnosis) across ethnicity, handedness, and gender, chi-square analyses for differences were conducted. Chi-square indicated a significant difference between groups on gender [χ^2 (2, N=93) = 13.59, $p < .01$]. Follow-up Chi-squares using the Bonferroni correction revealed that with regard to the gender differences, the No Diagnosis group differed significantly from the ADHD group ($p < .001$) such that significantly more males were identified as ADHD. These gender differences are consistent with epidemiological studies of ADHD (see Mash & Barkley, 1996). In addition, the PI group was comprised of only male participants and was significantly different from the CT group [χ^2 (1, n=38) = 4.15. $p < .05$], the No Diagnosis group [χ^2 (1, n=42) = 12.27. $p < .001$], and the Other Clinical diagnosis group [χ^2 (1, n=42) = 5.53. $p < .05$]. No differences between groups were revealed for handedness or ethnicity.

Table 1

Demographic Data for Sample

Source	No Diagnosis	ADHD-CT	ADHD-PI	Other Clinical	Total
Gender					
Male	12	18	14	19	63
Female	15	6	0	9	30
Ethnicity					
White	20	20	11	23	74
African-American	3	2	2	4	11
Hispanic	3	2	1	1	7
Asian	1	0	0	0	1
Handedness					
Left	1	2	3	5	11
Right	26	22	11	23	82

Note. ADHD=Attention Deficit Hyperactivity Disorder; PI=Predominantly Inattentive; CT=Combined Type.

Effects of Age, Parental Educational Level, and IQ

One-way ANOVAs were used to investigate differences between the groups across age, parent educational level, and IQ (Table 2 and Table 3). Significant IQ effects were revealed ($p < .01$; see Table 3). Post hoc tests (Tukey HSD) indicated that the No Diagnosis groups had significantly higher mean IQ scores than did the PI (p=.003) or Other Clinical groups (p=.002). The CT group obtained the next highest mean IQ score with no significant differences from the other groups followed by the Other Clinical and PI groups, respectively. Effect sizes were calculated using the mean differences and the population standard deviation of 15. The standardized effect size was moderate to high for the Other Clinical group ($\eta^{2=}$.78) and high for the PI group ($\eta^{2=}$.90). No differences were indicated for age and highest obtained parental education level (Table 2).

Table 2

Differences of Age and Parent Educational Level across Groups

Source	Mean	*SD*	*N*	*F*	*p*
Age	11.74	2.07	93	1.21	.31
No Diagnosis	11.49	2.21	27		
Combined Type	11.36	1.91	24		
Predominantly Inattentive Type	12.57	1.87	14		
Other Clinical	11.88	2.11	28		
Parent Educational Level	15.00	2.36	92	1.86	.14
No Diagnosis	15.88	2.34	26		
Combined Type	14.83	2.30	24		
Predominantly Inattentive Type	14.71	2.16	14		
Other Clinical	14.46	2.41	28		

MANOVA techniques were employed to further investigate group differences across IQ. Analyses were extended to include Verbal and Performance IQ means. After Bonferroni correction, analyses revealed no significant differences between groups on Verbal IQ (p=.03). A significant difference was indicated between groups on the Performance IQ ($p < .001$; see Table 3). Post hoc tests of the Performance IQ analyses revealed an identical profile to the gender effects analysis with the No Diagnosis group being significantly different from the Other Clinical and PI groups, respectively.

Table 3

Differences of IQ across Groups

Source	Mean	*SD*	*N*	*F*	*p*
Full Scale IQ	102.19	12.45	93	6.31	.001
No Diagnosis	109.52	13.96	27		
Combined Type	102.58	10.75	24		
Predominantly Inattentive Type	96.07	8.46	14		
Other Clinical	97.86	10.74	28		
Verbal IQ	102.66	13.30	93	3.14	.03
No Diagnosis	108.81	14.80	27		
Combined Type	101.50	11.52	24		
Predominantly Inattentive Type	97.93	11.88	14		
Other Clinical	100.07	12.37	28		
Performance IQ	101.63	13.11	93	6.63	<. 001
No Diagnosis	108.93	13.29	27		
Combined Type	103.42	11.70	24		
Predominantly Inattentive Type	95.36	9.05	14		
Other Clinical	96.21	12.35	28		

Note. ADHD=Attention Deficit Hyperactivity Disorder; PI=Predominantly Inattentive; CT=Combined Type; Parental Educational Level=highest number of years completed by either parent; Alpha set at .01 for all analyses

The standardized effect size was moderate to high for the Other Clinical group ($\eta^{2=}$.85) and high for the PI group ($\eta^{2=}$.90). No differences between the CT and the other groups were revealed. No differences were indicated for the PI and Other Clinical groups.

Procedures

All individuals participated in a comprehensive assessment including cognitive abilities, school achievement, language, memory, executive function, attention, behavior, and emotional functioning (see Table 4). Doctoral level students in school or counseling psychology who were supervised by a licensed psychologist, or a licensed psychologist, administered all assessment measures. Evaluations were conducted at a clinic at a large university located in a small metropolitan community in the southwest. Measures in the battery were given in a random order; test sessions varied in length based on the individual being assessed. Of the children in this study, thirty individuals were previously diagnosed ADHD. Thirty individuals were previously diagnosed ADHD. For any participants who had a previous diagnosis of ADHD and were prescribed stimulant medication (n=22), parents were asked to consult physicians before omitting medication prior to evaluation; in many cases, evaluations were conducted when the child or adolescent would not normally take the stimulant medication (e.g., school vacation, weekend) to facilitate this. If the child or adolescent was taking any other type of medication (e.g., Albuterol®), the child continued to take the medication as prescribed and the medications were noted. In the sample, 41.9% (n=29) of the children and adolescents were prescribed medication at the time of their evaluation. The medications prescribed included Ritalin® (*n*=8), Adderall® (*n*=6), Concerta® (*n*=8), Paxil® (*n*=1), Albuterol® (*n*=3), Wellbutrin® (*n*=1), and Zyrtec® (*n*=2).

Table 4

Measures Used in the MAPS Project

Domain	Instruments
History	Behavioral Assessment System for Children-Structured Developmental History
IQ	Wechsler Intelligence Scale for Children–Third Edition
Language	Peabody Picture Vocabulary Test-Third Revision, Expressive Vocabulary Test
Executive Function	Gordon Diagnostic System, Conners' Continuous Performance Test-Second Edition, Trail Making Test A&B, Wisconsin Card Sorting Test, Stroop-Color Word Test, Clock Face Drawing, Comprehensive Complex Figure Test, Drexel Tower of London, Verbal Fluency, Torrance-Figural Fluency, Behavior Rating Inventory of Executive Functioning, Children's Executive Functioning Scale, Conners' Rating Scale
Memory	Children's Memory Scale
Achievement	Woodcock Johnson-Third Edition
Behavioral/ Emotional Status	Behavioral Assessment System for Children Self & Parent forms, Children's Depression Inventory, State-Trait Anxiety Inventory for Children, Conners' Rating Scale-Revised, Diagnostic Interview for Children and Adolescents-IV Computer Program

Every effort was made to obtain both parent and teacher ratings, however, this was not always feasible. Of the participants, 71% (*n*=66) of teacher ratings were returned and completed. The parents of each participant received an individual assessment report of the evaluation upon completion. Participants may or may not have been previously diagnosed as having a disorder; however, for the purposes of consistency in diagnostic procedures across participants, the presence of any previously diagnosed learning, attention, or psychological disorder was reevaluated using procedures outlined below.

At least two researchers (doctoral level graduate students and one licensed psychologist) provided diagnostic impressions based on assessment of intelligence, school achievement, expressive and receptive language measures, parent, teacher and self-report rating scales, parent responses to the Diagnostic Interview for Children and Adolescents-Computer Program (DICA–IV; Reich, Welner, & Herjanic, 1997), background information provided by parents, and criteria from the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition Text Revision* (DSM IV-TR; APA, 2000). The individuals involved in the diagnostic process were naïve to the results on dependent variables related to executive function. This process used an internal form with a specific format following the multi-axial system. Inter-diagnostician reliability was .84 (Cohen's Kappa); for the three groups of ADHD, Other Clinical, and No Diagnosis. Cohen's Kappa for ADHD subtypes was .93 and the proportion of agreement was .97.

Instrumentation

As evident in Table 4, a number of measures routinely used in the assessment of children and adolescents were administered. Of particular interest to this study are those measures that comprise the dependent variables related to executive function. These will be described here within the context of the domain they were expected to be measuring. Dependent variables by domains of interest are provided in Table 5.

Table 5

Dependent Measures by Domains

Inhibition	Working Memory	Planning	Attention
Stroop Color-Word Score	WISC III Digits Backward	TOL^{DX} Total Time	GDS Distract. Correct
Commission Errors of CCPT-II	CMS Sequences	TOL^{DX} Total Moves	GDS Vigilance Correct
GDS Vigilance Commission Errors	Letter Fluency (F-A-S)	WCST Categories Achieved	Omission Errors of CCPT-II
BRIEF Inhibit	BRIEF Working Memory	BRIEF Plan/Organize	WCST Failure to Maintain Set

Note. WISC-III=Wechsler Intelligence Scale for Children-Third Edition; TOL^{DX}=Tower of London Drexel Edition; GDS=Gordon Diagnostic System; CCPT-II=Conners' Continuous Performance Test-II; WCST=Wisconsin Card Sorting Test; BRIEF=Behavioral Rating Inventory of Executive Function; Distract.=Distractibility.

Inhibition

Measures of inhibition were selected based on comprehensive literature review. The measures included the Stroop (Golden, 1978) Color-Word task, Conners' Continuous Performance Test–II (Conners, 1998) commission errors, the Gordon Diagnostic System (GDS; Gordon, 1983) vigilance commission errors, and Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworth, 2000) Inhibit Scale. Each of these is described in more detail.

Stroop task. The Stroop task is comprised of three conditions each lasting for 45 seconds (Golden, 1978). First the child reads the color names aloud as quickly as possible, next the child names the color of printed X's, and lastly, the child names the color of ink the word is printed in, ignoring the over learned or prepotent response of reading the color name. The Stroop test yields four raw scores that can be converted to T-scores: the Word score, the Color score, the Color-Word (CW) score, and a derived Interference score. Scores for children and adolescents through age 16 years are age-corrected except for the Interference score. Test retest reliability ranges from .86 for the Word score to .73 for the CW and CW predicted scores; no reliability information is available for the derived interference score.

The CW score has been found to be sensitive to disinhibition in children and adolescents with ADHD, and distinguished ADHD groups from controls in ten out of twelve studies conducted (see Riccio, Homack, Wolfe, Davis, & George (in press); Sergeant et al., 2002 for a review). When considering the diagnostic utility of selected neuropsychological assessment tools, Doyle et al. (2000) found the CW score to be the strongest discriminator of boys with ADHD from normal controls. Since the CW score has been shown to be sensitive to group differences in children, and has demonstrated reliability, it was used as a measure of inhibition in this study.

Conners' Continuous Performance Test-II. The Conners' CPT II (Conners, 1998) is a computer-administered measure that is 14 minutes long. The child is required to respond by pressing the space bar or mouse button when letters are shown on the screen and to inhibit responses when an "X" is the letter displayed. The use of a computer allows for precise measurements as well as variation in the pace of the stimulus presentation. The test manual does not report reliability information (see Riccio, Reynolds, & Lowe, 2001 for a review). Without reliability, information on the temporal stability of the CPT is unknown.

When considering specific scores obtained from CPTs in general, the best scores for discriminating ADHD from normal controls are omission and commission errors (Riccio et al., 2001). Rapport et al. (2000) reviewed literature comparing children with ADHD to normal controls and found that the Conners' CPT detected differences between groups in 18 out of 21 studies (86% of the time). The effect size was 0.85 when using CPTs. Omission errors generally are interpreted as reflective of attentional lapses, while commission errors are seen as reflecting disinhibition. Two other scores, derived from signal detection theory are sometimes used, D-prime is thought to represent the person's sensitivity or ability to detect the target (i.e., not respond to the letter X) and the beta score or response bias is thought to reflect the person's style of responding (i.e., impulsive or conservative). Since commission and omission errors were found to be the most sensitive scores for distinguishing normal controls from those individuals with ADHD (see Riccio et al., 2001 for review), they were used in this study. Specifically, for the purposes of this study the commission errors score was used a measure of inhibition.

Gordon Diagnostic System. The Gordon Diagnostic System (GDS; Gordon, 1983) also is a CPT. It is the oldest and one of the most commonly used CPTs (Riccio et al., 2001). The GDS does not require a computer to administer; it is a self-contained microprocessor. The children's version has three 8-to 9-minute long conditions; delay, vigilance, and distractibility tasks. The delay task is divided into four time blocks to track responses. A child is told to push the button, then wait, and push it again; however, if the child does not wait "long enough", he will not receive a point. The delay is 6 seconds.

The next condition is the vigilance task. The child watches a display screen and presses a button every time a "1" is displayed before a "9". Although there are two versions of the vigilance task that can be given to children between 6 and 16 years of age (1/9 and 3/5 versions) only the 1/9 version was used. The task is divided into three scoring blocks. Number correct, omission errors, and commission errors are reported. The last condition is the distractibility task. This task is similar to the vigilance task except numbers are displayed on three adjacent screens and the child is instructed to attend only to the center screen and respond to the 1/9 condition. All conditions yield scores reflecting variability of performance across time, as well number of correct responses and errors.

Scores are interpreted by the use of cut scores based on the standardization data. A score occurring in the 5^{th} percentile or less is abnormal, 5^{th} – 25^{th} percentile is borderline, and above the 25^{th} percentile is normal. The manual reports that several variables have skewed distributions. Means and standard deviations are available. For this study, raw scores for the GDS variables of interest were converted to standard scores with a mean of 100 based on norms provided in the manual (Gordon, 1983).

The vigilance task commission errors will be included as a measure of inhibition. The vigilance commission errors test-retest reliability is reported to be .84 for a nonclinical sample and .94 for clinical samples (Gordon & Mettelman, 1988). Riccio et al. (2001), in a comprehensive review of the literature, found children with ADHD performed significantly worse on CPT measures than did normal controls. Across studies of children with ADHD, commission errors were the best discriminator followed by omission errors.

Behavior Rating Inventory of Executive Functioning Inhibit Scale. The Behavior Rating Inventory of Executive Functioning (BRIEF; Gioia et al., 2000) is a relatively new rating scale with parent and teacher versions. The manual reports validity and reliability studies supporting its use and utility in assessing children with ADHD and other disorders. The questionnaire is designed for children ages 5 to 18 years. Eighty-six items comprise eight clinical scales: Inhibit, Shift, Emotional Control, Initiate, Working memory (WM), Plan/Organize, Organization of Materials, and Monitor. These scales yield two Index scales, Behavioral Regulation and Metacognition, in addition to an overall Global Executive Composite. Negativity and Inconsistency Scales assist clinicians in detecting invalid or suspect results. Respondents indicate whether the specific behavior has never, sometimes, or often been a problem within the last 6 months. T-scores are used for interpretation and scores above 65 are considered as possibly clinically significant. Internal consistency for the Inhibit Scale is .91 (normative sample) and 0.94 (clinical sample) for the parent version. Retest reliability with three weeks between administrations ranged from .76 for parents' ratings of children with clinical disorders to .91 for teachers rating of normative children. As reported in the manual, the Inhibit and the Working Memory scales are the most sensitive and specific when diagnosing children with ADHD. The authors recommend using a T-score of 70 for diagnoses. Using this cutoff, 85% of children with ADHD were identified correctly, while 13% of controls were not. As not all children have teacher ratings, parent results on the BRIEF were used; for inhibition, the Inhibit Scale was used.

Working Memory

Measures of working memory also were selected based on the review of literature. The Wechsler Intelligence Test for Children–Third Edition (WISC-III: Wechsler, 1991) digits backward, the Children's Memory Scale (CMS; Cohen, 1997) Sequences subtest, the Letter Fluency (F-A-S) test (Gladsjo, Miller, & Heaton, 1999), and Parent ratings on the Behavior Rating Inventory of Executive Functions (BRIEF) Working Memory subscale were used.

Wechsler Intelligence Scale for Children-III Digit Span backwards. The Digit Span backwards on the WISC-III was used as a measure of working memory. Factor analytic studies have shown that the recall of digits in reverse order (digits backward) from their presentation is distinct from the recall of digits forward. Although both are thought to have a sequential processing component, digits forward and digits backward clearly do not tap the same memory processes (Ramsay & Reynolds, 1995; Reynolds, 1997). Significant differences on digits have been found in six out of ten studies when children with ADHD were compared to controls (Rapport et al., 2000). Unfortunately, it is not known which scoring method was used (digits forward and digit backwards or digits backward only). Perugini et al. (2000) also found that groups (ADHD, controls) differed on digit span (effect size of 0.70). However, when examining digits forward and digits backward separately, group differences were noted for digits forward, but not for digits backward.

Children's Memory Scale Sequences subtest. The Children's Memory Scale (CMS; Cohen, 1997) includes six subtests in its core battery. The CMS Sequences subtest will used as a measure of working memory. The Sequences subtest is timed and children are asked to recite commonly known lists (i.e. the alphabet, days of the week, months of the year, and various counting tasks) both forward and backward. The last item is an oral trails task in which the child recites the alphabet and counts alternately (A, 1, B, 2). Item scores account for speed and accuracy; however, bonus points for speed are awarded only when the response is correct. The CMS was designed for use with children from 5 to 16 years of age. Stability coefficients for the Sequences subtest are .80 for children (9-12 years of age) and .89 for adolescents (13-16 years of age).

The Sequences subtest is very similar to the Mental Control Subtest of the Wechsler Memory Scale–III used for adults. One study used the Mental Control subtest with children (Pineda et al., 1998) and found the largest difference between normal control and the ADHD groups on this subtest of any of the neuropsychological measures included in the battery. The standardized discriminant coefficient was -.81 for the sample. No other studies were located that examined the Mental Control or Sequences subtest.

Letter fluency task. The Letter Fluency task (F-A-S; Gladsjo et al., 1999) is a very simple, easy to administer test of verbal fluency. Children are given one minute to name as many words as can they can for each letter (/f/a/s/), excluding proper nouns and plurals. Several factor analytic studies found that the F-A-S loaded on factors interpreted as working memory (e.g. Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Pineda et al., 1998); others have described the task as tapping processing speed, vocabulary knowledge, semantic memory, and inhibition, set maintenance, as well as working memory (e.g. Sergeant et al., 2002). The letter fluency task appears to discriminate children with ADHD from controls better than the category fluency task. For example, differences in verbal fluency were indicated in six out of nine studies reviewed while the categories test found differences between groups in only two out of nine studies (Sergeant et al., 2002). In a study of neuropsychological tests frequently used to assist in diagnosis of ADHD, Grodzinsky and Barkley (1999) found the F-A-S task to have good positive predictive power, correctly identifying 90% of children with ADHD. However, 68% percent of children with ADHD scored in the normal range indicating low sensitivity. In another comprehensive review, only half the studies reviewed found significant differences between groups (ADHD, controls) suggesting questionable clinical utility of the F-A-S (Rapport et al., 2000).

Behavior Rating Inventory of Executive Functioning Working Memory Scale. As previously described, the BRIEF is a relatively new rating scale with parent and teacher versions (Gioia et al., 2000). The Working Memory subscale items measure "the capacity to hold information in mind for the purpose of completing a task" (Gioia et al., 2000, p. 19). The BRIEF manual states that working memory is used when doing multi-step tasks, including mental arithmetic and following directions. The internal consistency for the parent form is .92 for clinical groups and .89 for the normative sample. The authors include the ability to sustain attention as a component of the Working Memory scale. They acknowledge the problem of separating attention from other more complex or higher cognitive processes. The manual reports the Working Memory scale to be one of the most sensitive and specific for diagnosing children with ADHD, recommending a T-Score of 70 as providing the best sensitivity and specificity for the Working Memory scale (74% and 13% respectively).

Planning/Problem Solving

Executive function is a multidimensional construct, often containing subcomponents such as inhibition, attention, and working memory, planning and problem solving. Therefore, measures of planning and problem solving skills, strategy use, and action selection also were included in the study. Two measures frequently used as measures of problem solving and planning skills are the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993), and tower tasks. Although a variety of tower tasks have been used as a measure of planning, until recently, adequate normative data for children were was not available. The recently developed Tower of London Drexel Version (TOL^{DX}; Culbertson & Zillmer, 1999) may be a more useful measure of planning and problem skills because of its improved standardized procedures and norms. WCST variables, as well as the TOL^{DX} total move and total time scores were used in conjunction with the BRIEF Plan/Organization Scale as measures of planning and problem solving.

Drexel Tower of London. The TOL^{DX} is an individually administered neuropsychological measure thought to measure problem solving and "executive planning" in children and adults (Culbertson & Zillmer, 1999; p. 3). The TOL^{DX} consists of two boards, each having three pegs. Examiners arrange red, green, and blue beads on their pegs. Examinees are to move their beads from an original starting position to match the position of the examiners beads in as few moves as possible. Participants are only allowed to move one bead at a time, and cannot place more beads on a peg than it will hold. Rule violations are noted as well as time violations. The total number of moves is recorded. Initiation and executive times also are tracked. The initiation time is the latent time between when the instructions are given and the examinee makes his/her first move. The execution time is the amount of time it takes the examinee to complete the problem and the total time includes both the initiation (planning time) and the execution time. The number of problems solved in the least amount of moves possible also yields a standard score. Six scoring variables are used to interpret performance differences. The raw scores are transformed into standard scores for normative comparisons. The manual does not report specific reliability coefficients for test retest; however, reliabilities are reported to range from moderate to high.

When examining the relationship of the TOL^{DX} to other neuropsychological measures, Culbertson and Zillmer (1998a) report that the TOL^{DX} (total move, time violations and rule violation) scores loaded with the Stroop CW interference score and on a second factor that included scores from the Wisconsin Card Sorting Test (perseverative response and number of categories completed). These findings suggest that inhibition, planning, and problem solving are components that impact performance on the TOL^{DX}. Recent studies of inhibition and planning with different versions of the TOL were equivocal (Mitchell & Poston, 2001; Phillips, Wynn, Gilhooly, Della Saga & Logie 1999; Phillips, Wynn, McPherson, & Gilhooly, 2001). However, it is difficult to interpret these findings in relationship to the validity of the TOL^{DX}.

The TOL^{DX} differs from the original Tower of London (Shallice, 1982) by the inclusion of additional scoring dimensions, more difficult items that increased the ceiling with 6-and 7-move problems, improved standardization and expanded normative information. These changes attempted to address some of the shortcomings of other tower tasks. As reported in the manual, children with ADHD do not perform as well as normal controls; they use more moves, take longer to complete problems, and have more rule violations (Culbertson, & Zillmer, 1999). In another study, intercorrelations indicated that the initiation time was negatively related to the total move score, while there was a positive relationship for the number of total moves and the total time it took participants to solve the problem or total execution time (Zillmer, Culbertson, & Holda, 1997). Interestingly, the total move score and the time variables do not have significant associations with each other. Children with ADHD may use more moves and have longer problem solving times because they do not adequately plan ahead, but rather begin to solve the problem by using a trial and error strategy, thus needing more moves and time to complete the problems. For this study, the total moves score and the total time were used as measures of planning abilities.

Wisconsin Card Sorting Test- Categories completed. The Wisconsin Card Sorting Test (WCST; Heaton et al., 1993) manual reports studies supporting its utility in assessing executive function, specifically with children diagnosed with ADHD. The WCST requires the child to discern the sorting criteria (color, figure, or number) of a set of cards based upon feedback from the examiner. The examiner tells the child whether they are “correct” or “incorrect” after they place the card. When the child obtains 10 consecutive correct matches, the examiner changes the matching criterion. The matching process occurs six times or until all of the 128 cards are administered, whichever occurs first.

The WCST yields 15 scores. Children with ADHD complete fewer categories when compared to normal controls (Barkley, Grodzinsky & DuPaul, 1992; Boucugnani & Jones, 1989; Chelune, Ferguson, Koon, & Dickey, 1986; Doyle et al., 2000). In 17 out of 26 studies using the WCST, there were significant differences between ADHD and normal controls (Sergeant et al., 2002). In another review, 10 out of 18 studies had significant differences between the children with ADHD and controls (Rapport et al., 2000). Differences in scores used may impact the usefulness and sensitivity of the

WCST. As reported by Doyle et al. (2000) the categories completed indicated the highest positive predictive power (PPP) of all the assessment tools they evaluated. However, another study reported PPP of less than 50% for all the scores yielded by the WCST (Grodzinsky & Barkley, 1999). Pennington et al. (1996) suggested that the WCST is sensitive to abnormal planning; however; it appears to have ceiling effects or it may be a poor measure of normal variation. Pennington et al. noted that the WCST had high reliability with individuals with planning difficulties, but was less reliable with normal individuals. Similarly, a meta-analytic review found the WCST to have good sensitivity but to lack specificity (Romine et al., 2002). Although the WCST appears to have diagnostic utility, further research is needed. Based on available research, the categories completed variable was used as a measure of planning.

Behavior Rating Inventory of Executive Functioning Plan/Organize scale. From the BRIEF, the Plan/Organize subscale will be used to assess problem solving and planning abilities. The scale measures “the child’s ability to manage current and future-oriented task demands” (Gioia et al., 2000, p. 19). As with other tasks that are thought to tap planning skills, there is a sequential component to planning as measured by the BRIEF. Although organization was originally intended as a separate scale, after examining the factor structure, the authors determined that organization and planning were not distinct and combined the scales (Gioia et al., 2000). Internal consistency was .91 for the clinical sample and .90 for the normative sample.

Attention

Similar to inhibition and working memory, attention has been conceptualized as a multifaceted construct. For the purposes of this study, attention includes sustaining and maintaining alertness. CPTs were designed to measure attention and vigilance. Three scores from the two CPTs were included; omission errors from the Conners' CPT-II and the number correct for the vigilance and the distractibility tasks from the GDS. One other measure included in the domain was the WCST failure to maintain set score.

Gordon Diagnostic System Vigilance and Distractibility number correct. The two scores from performance on the GDS to be used as measures of attention are the Vigilance and Distractibility number correct. Both tasks require sustained attention and detection in the presence of distracters; however, correlations between these tasks indicate that the tasks are not identical. Associations between tasks range from -.22 to .06 (Gordon & Mettelman, 1988).

Conners' Continuous Performance Test-II Omission errors. The Omission errors score from the Conners' CPT will also was included as a measure of attention. Barkley et al., (2001) conducted a factor analytic study of CPT scores. CPT omission errors, variability of standard error, and hit rate standard error loaded on the first factor while CPT commission errors and hit rate comprised another factor. The authors characterized the first factor as inattention and the second factor as inhibition. Thus, omission errors score will be included in the attention domain score.

Wisconsin Card Sorting Test failure to maintain set. The WCST failure to maintain set score may reflect ability to sustain attention.   Researchers have suggested the WCST is a multifactorial test requiring several cognitive processes that need to be assessed independently (Anderson, Damasio, Jones, & Tranel, 1991). Processes involved may include problem solving abilities, use of feedback, strategy modification, shifting or flexibility and inhibition (Sergeant et al., 2002). When investigating the WCST's structure, Greve et al. (1993) and Greve, Williams, Haas, Littell, & Reinoso, (1996) found a two-factor solution. The first factor was interpreted as problem solving skills; the second factor-contained failure to maintain set and was thought to capture attentional processes. The two factors account for 91% of the variance in scores. Pineda, Ardila, and Rosselli (1999) found significant differences between children with ADHD and non-ADHD children on the failure to maintain set score reflecting attentional problems. Based on discriminant function analysis, they recommended the inclusion of the failure to maintain set score in neuropsychological test batteries for assessing children for ADHD. As such, it will be included as a measure of attention.

Statistical Analyses and Procedures

This study was a between subjects design with nonequivalent groups (Cook & Campbell, 1979). Differences were examined on the dependent variables between four groups of children and adolescents -those with ADHD (Predominantly Inattentive Type (PI) and Combined Type (CT), those with some Other Clinical diagnosis, and those with No Diagnosis. Differences between groups on measures used to determine group membership are reported; however, group comparisons on the dependent measures are the focus of the investigation. An experimentwise alpha level .05 for testing of significant differences should be sufficient to control the Type I error rate (Cohen &

Servan-Schreiber, 1992); however, a Bonferroni correction was used to control for the experimentwise error rate with multiple comparisons with alpha set at .01.

Many research studies have not found that single scores are diagnostic, but that aggregated scores for specific domains are more useful (Doyle et al., 2000; Grodzinsky & Barkley, 1999; Perugini et al., 2000; Rapport et al., 2000). Executive functioning is a hypothetical multicomponent construct that cannot be well measured by a single indicator. Kline (1998) suggested that such a construct cannot be measured with a single score for the following reasons. A single score or measure would not be completely free from random error and not all of the systematic portions of an indicator's variance may reflect the construct or, in this case, executive functions of interest in this study (Inhibition, Attention, Working Memory and Planning). Kline (1998) recommended using multiple indicators of each construct as multiple indicators improve reliability and may tap different facets or components of the constructs. As recommended and as has been done in previous studies, scores from the measures for each domain (Inhibition, Attention, Working Memory, and Planning) were transformed to a standard score with a mean of 100 (*SD*=15) using z-score linear transformation such that lower standard scores are indicative of problems/deficits for consistency. Standard scores for each domain were averaged to yield a "domain" score. Examination of domain scores as well as results of research questions are presented in Chapter IV along with supplemental analyses. Results and implications are presented in Chapter V.

CHAPTER IV

RESULTS

As stated earlier, this study investigated specific domains of executive function in relation to ADHD. In this chapter, the results of this study are presented. Following the presentation of results, the implications and conclusions are presented in Chapter V.

Preliminary Analyses

Assumptions and requirements, such as linearity, normality and homoscedasticity for Multivariate Analysis of Variance (MANOVA) analyses (Bordens & Abbott, 1996), were examined; other considerations include the presence of outliers. Violations of these assumptions and outliers may require adjustment to the data set including transformation of the data and data “trimming” (Bordens & Abbott, 1996; Kline, 1998; Tabachnick & Fidell, 1996).

The sixteen dependent variables to be aggregated into the four domain scores were analyzed for skewness and kurtosis. The Gordon Diagnostic System vigilance task total commissions raw scores were positively skewed (skewness=5.61; kurtosis=40.63) with three outliers below three standard deviations from the mean. The obtained score distribution was consistent with those reported in the GDS manual for the standardization sample (Gordon, 1983). The manual suggests using percentiles when conducting research; however, using percentiles would not be appropriate when comparing standard scores. Alternate methods were employed to address the distribution of the scores of this variable.

Table 6

Descriptive Statistics for All Measures

Measures	*N*	Mean	*SD*	Skewness	Kurtosis
Inhibition	89				
Stroop Color-Word	92	91.38	12.53	-.44	.72
CCPT-II Commission errors	92	101.94	17.06	.39	-.33
GDS Vigilance Commissions	91	96.72	15.34	-1.49	1.77
BRIEF-Inhibit	93	84.48	23.52	-.51	-.69
Working Memory	91				
Digit Span Backward	91	98.76	13.43	.50	-.03
CMS-Sequences	93	97.98	13.03	.22	.40
Letter Fluency	93	94.11	16.87	.21	-.80
BRIEF-Working Memory	93	78.29	19.50	.15	-.53
Planning	93				
TOL^{DX} Total Time	93	99.80	14.04	-.96	.67
TOL^{DX} Total Moves	93	97.59	13.69	-.46	-.28
WCST-Categories Obtained	93	102.44	15.39	-1.90	3.50
BRIEF-Planning	93	79.68	19.60	.40	-.64
Attention	87				
GDS Distractibility	90	92.19	22.47	-1.18	1.11
GDS Vigilance correct	91	84.90	36.19	-2.27	5.64
CCPT-II Omission errors	92	97.78	16.67	-1.77	3.60
WCST-Failure to Maintain Set	91	102.23	13.86	-.92	.54
Valid N (listwise)	84				

Note. CCPT-II=Conners' Continuous Performance Test-II; GDS=Gordon Diagnostic System; BRIEF=Behavior Rating Inventory of Executive Functioning; CMS=Children's Memory Scale; TOL^{DX}=Drexel Tower of London; WCST=Wisconsin Card Sorting Test.

First, a square root transformation was attempted to correct the shape of the distribution; skewness should be no greater than |3.00| and kurtosis should be no greater than the |8.00| for MANOVA techniques (Kline, 1998). Although the transformation improved the shape of the distribution, the score distribution still violated assumptions (skewness=-2.81, kurtosis=10.95). Another method of addressing skewness and kurtosis is to address outliers that are more than three standard deviations (*SD*) from the mean (Bordens & Abbott, 1996; Tabachnick & Fidell, 1996). The scores approached a normal distribution when the data were trimmed with the three scores (SS=-0.54, 304 errors; SS=40.64, 127 errors; SS=41.98, 98 errors) set at three *SD* (SS=55) from the mean. After restricting the outlying scores for the GDS vigilance commission total errors to three *SD* from the mean, the skewness (-1.49) and kurtosis (1.78) were within an acceptable range. None of the other 15 variables required transformations to address skewness or kurtosis (Table 6).

For consistency, the remaining 15 variables were screened for outliers. Any observations exceeding three standard deviations from the mean were set at three standard deviations (minimum=55; maximum=145). This procedure retains the extreme observations without those observations having undue influence on the analyses. The data requiring trimming was a relatively small percentage across the 16 variables (54 observations; 3.77 %). Following data trimming procedures, the multivariate normality was tested with Mardia's PK (1970) normalized test for multivariate kurtosis. A value less than 3 is recommended for an assumption of multivariate normality (Hutcheson & Sofroniou, 1999). Mardia's PK was 1.01 for all 16 variables. Next, the standard scores were aggregated into the four domain scores (Inhibition, Working Memory, Planning and Attention) based on the theoretical conceptualizations as explained and tabled in Chapter III (see Table 5).

Descriptives of the subtest or tasks that comprise the domains and the domain are summarized in Table 6 and Table 7. With 16 observed variables and 93 subjects, there were 14 missing observations across the data set; one missing observation for three variables, three missing observations for one variable, and four missing for observations two variables. To address issues of missing data, four domain scores for Inhibition, two domain scores for Working Memory, and four domain scores for Attention were prorated. Using a prorated mean for the domain score allowed those participants to be included in the analyses. To prorate domain scores, if three out of the four variable scores that were to comprise a domain score were available, the mean of the three variables was used as the domain score. Two participants could not be included because in one domain they were missing data on two variables within a single domain. These data points were not available because of administration errors. Analyses were first completed excluding participants with missing domain scores (Table 7). Subsequent analyses included the participants with prorated domain scores (Table 8).

Table 7

Trimmed Data Descriptive Statistics for All Measures and Domains

Measures	*N*	Mean	*SD*	Skewness	Kurtosis	R^2
Inhibition	89	94.20	9.19	.08	-.54	
Stroop Color-Word	92	91.54	12.48	-.39	.66	.35
CCPT-II Commission Errors	92	101.66	17.38	.23	-53	.28
GDS Vigilance Commissions	91	97.45	13.87	-1.49	1.77	.48
BRIEF-Inhibit	93	86.32	20.91	-.16	-1.31	.62
Working Memory	91	92.63	9.80	.25	.78	
Digit Span Backward	91	98.98	14.84	.35	.86	.24
CMS-Sequences	93	97.80	13.34	.29	.33	.45
Letter Fluency	93	94.00	16.53	.20	-.76	.32
BRIEF-Working Memory	93	79.24	17.61	.42	-.70	.72
Planning	93	94.76	8.62	-.36	.79	
TOL^{DX} Total Time	93	99.25	14.60	-.95	.37	.36
TOL^{DX} Total Moves	93	96.32	14.17	-.38	-.52	.29
WCST-Categories Obtained	93	103.02	14.42	-1.70	2.22	.29
BRIEF-Planning	93	80.47	18.46	.59	-.65	.76
Attention	87	96.43	10.77	-61	.06	
GDS Distractibility	90	94.31	19.94	-.75	-.57	.42
GDS Vigilance Correct	91	92.41	19.76	-.77	-.67	.51
CCPT-II Omission errors	92	97.79	15.18	-1.27	.86	.38
WCST-Failure to Maintain Set	91	102.58	13.61	-.96	.65	.29
Valid N (listwise)	84					

Note. CCPT-II=Conners' Continuous Performance Test –II; GDS=Gordon Diagnostic System; BRIEF=Behavior Rating Inventory of Executive Functioning; CMS=Children's Memory Scale; TOL^{DX}=Drexel Tower of London; WCST=Wisconsin Card Sorting Test.

Table 8

Trimmed Data Descriptive Statistics for Domains with Missing Values

Measures	*N*	Mean	*SD*	Skewness	Kurtosis
Inhibition	93	94.22	9.08	.09	-.51
Working Memory	93	92.41	9.83	.27	.73
Planning	93	94.62	8.77	-.37	.67
Attention	91	96.77	10.66	-.68	.14

In addition to basic statistical assumptions, the variables that comprise the domains were examined to determine the most appropriate combination of scores to effectively differentiate between groups in this sample. To this end, the correlations of the subtests within each domain and across domains were examined (Table 9).

The domain scores, which are components of Executive Functioning, are significantly related to one another. Given that Inhibition, Working Memory, Planning and Attention are conceptualized as constructs under the umbrella of Executive Functions, they should have both convergent and discriminant validity such that they should be related but discrete functions. Therefore, the domains should be correlated but not redundant measures or too highly correlated (Kline, 1998). The correlations between domains are small to moderate (Cohen, 1988) as would be expected.

Table 9

Correlations of Subtests and Domain Scores for the Total Sample

Measures	Inhibition	Working Memory	Planning	Attention
Inhibition	1.0	.26*	.31**	.38**
Stroop Color-Word	.45**	.37**	.19	.16
CCPT-II Commission Errors	.65**	-.15	.02	.13
GDS Vigilance Commissions	.59**	-.01	.11	.47**
BRIEF-Inhibit	.56**	.36**	.30**	.14
Working Memory	.26*	1.0	.36**	.28**
Digit Span Backward	.04	.58**	.08	.14
CMS-Sequences	.05	.72**	.26*	.20
Letter Fluency	.06	.67**	.21*	.23*
BRIEF-Working Memory	.44**	.57**	.33**	.14
Planning	.31**	.36**	1.0	.30**
TOL^{DX} Total Time	-.08	.15	.59**	.10
TOL^{DX} Total Moves	.16	.06	.61**	.14
WCST-Categories Obtained	-.01	.12	.56**	.37**
BRIEF-Planning	.52**	.42**	.49**	.08
Attention	.38**	.29**	.30**	1.0
GDS Distractibility	.18	.18	.23*	.75**
GDS Vigilance Correct	.30**	.18	.21*	.76**
CCPT-II Omission errors	.40**	.13	.09	.65**
WCST-Failure to Maintain Set	.02	.27*	.10	.23*

Note. CCPT-II=Conners' Continuous Performance Test-II; GDS=Gordon Diagnostic System; BRIEF=Behavior Rating Inventory of Executive Functioning; CMS=Children's Memory Scale; TOL^{DX}=Drexel Tower of London; WCST=Wisconsin Card Sorting Test; *p < .05 (2-tailed) **p < .01 (2-tailed)

With regard to the variables selected to comprise the domain scores, 14 out of the 16 selected have the highest correlations with the domain that they were placed in based on the review of research as summarized in Chapter III. The measures that comprise the Inhibition, Working Memory, and Planning have moderate to high correlations with their respective domains scores. For the Attention domain score, the WCST failure to maintain set standard score has a small correlation with the Attention domain (r=.23), it also has a larger but still small correlation with the Working Memory domain (r=.27). These correlations suggest that the WCST failure to maintain set standard score may not reflect or tap the domains of executive functions as conceptualized in this study. In contrast, the BRIEF Planning scale was moderately correlated with the Inhibition, Working Memory, and Planning domains. The measure was selected as a measure of planning based on information and research cited in the manual; however, in this study, the Plan/Organize scale had higher correlations with the Inhibition domain (r=.52) than the Planning domain (r=.49) and a moderate relationship with the Working Memory domain (r=.42). These moderate to high correlations with multiple domains suggest that the Planning scale on the BRIEF may tap several domains of interest in this study.

To assess for multicollinearity, bivariate correlations between each variable and all the rest were examined (Appendix B). Kline (1998) suggested that bivariate correlations that exceed |.85| may need to be addressed to reduce redundancy. In this data set, the highest bivariate correlation between variables is .81. In general, the correlations between variables that are purported to be theoretically related are not consistently significant. This suggests that the theoretically derived combinations of measures used to create the domains may not be the most appropriate. While there is not a statistical test for multicollinearity, a large squared multiple correlation ($R^2 > .90$), a variance tolerance value less than 10%, and a large variance inflation factor (VIF > 10) are indicators of multicollinearity. The largest squared multiple correlation is .76 (Table 9). The smallest variance tolerance was .24, indicating that 24% of the "variance is not redundant with all the other variables" (Kline, 1998; p. 78). The VIF is the ratio of a variable's standardized total variance to its unique variance. The largest ratio was four, well below a ratio greater than 10. These estimates indicate that multicollinearity may not be an issue in the analyses.

Group Differences

Having initially examined the domain scores as determined theoretically in Chapter III, the derived domain scores were used to determine if children and adolescents with ADHD differ from normal controls on measures of Inhibition, Attention, Planning, and Working Memory (Research Question 1). In addition, it was determined if children and adolescents with ADHD (CT and PI subtypes) differed from children with Other Clinical (non-ADHD) diagnoses on measures of Inhibition, Attention, Planning, and Working Memory (Research Question 2).

Multivariate analysis of variance (MANOVA) procedures were conducted using SPSS 11.0 to test for significance between groups across domain scores. Given the interrelated nature of the dependent variables, a MANOVA was selected. MANOVA techniques consider the correlations among dependent variables and they can be more powerful than univariate analysis (Bordens & Abbott, 1996). MANOVAs were conducted using the derived domain scores (Inhibition, Attention, Planning and Working Memory) as the dependent variables and diagnostic status (PI, CT, No diagnosis, Other Clinical diagnosis) as the grouping variable to answer research questions 1 and 2. The ADHD group was expanded because preliminary analyses suggested that the ADHD group was not a unified group but differed across subtypes at least for gender. Further, Barkley (1999) theorized that PI and CT subtypes are different disorders. Initial analyses used the domain scores as conceptualized based on existing theory and research. As such, these analyses also address Research question 3 specific to subtypes.

Limited Sample, No Covariate

A 4 group (CT, PI, Other Clinical, and No Diagnosis) X 4 domain (Inhibition, Working Memory, Planning and Attention) MANOVA was conducted using only those participants with all 16 variables (N=84). The Wilks *lambda* F-test was used to determine significant multivariate effects. The MANOVA was significant for overall effects [F (3,80)=4.08, $p < .001$]; univariate results are presented in Table 10. Univariate post hoc tests (e.g., Tukey HSD for balanced designs) were conducted to identify the direction of group differences for the specific dependent variables that contributed to the multivariate effect.

Table 10

Dependent Variables by Group

Source	Mean	*SD*	*N*	*F*	*p*
Inhibition	94.35	9.06	84	6.70	>.001
No Diagnosis	99.05	8.94	24		
Combined Type	88.07	8.07	21		
Predom. Inattentive Type	94.74	8.18	12		
Other Clinical	94.87	7.79	27		
Working Memory	92.48	9.74	84	9.15	>.001
No Diagnosis	99.99	10.24	24		
Combined Type	89.41	8.78	21		
Predom. Inattentive Type	86.94	10.26	12		
Other Clinical	90.64	5.39	27		
Planning	95.04	8.66	84	4.62	.005
No Diagnosis	100.15	9.25	24		
Combined Type	92.05	6.95	21		
Predom. Inattentive Type	94.35	8.39	12		
Other Clinical	93.14	7.82	27		
Attention	96.38	10.95	84	.81	.012
No Diagnosis	98.26	13.03	24		
Combined Type	95.71	10.91	21		
Predom. Inattentive Type	95.72	13.43	12		
Other Clinical	95.54	7.77	27		

Note. Predom.=Predominantly

Given the number of comparisons being made alpha was set at $p < .01$ to decrease the likelihood of finding a difference when none exists (Type I error). Univariate post hoc results were significant for the Inhibition domain [F (3,80)=6.67, $p <$ .001], the Working Memory domain [F (3,80)=9.12, $p < .001$], and the Planning domain [F (3,80)=4.62, p =. 005]. There were no significant differences between groups for the Attention domain score [F (3,80)=0.321, p=.81].

For the Inhibition domain scores (Table 10), the CT group mean was significantly lower than the No Diagnosis group ($p < .001$). Standardized mean difference effect size was 1.23.That is the CT group evidenced more problems in the Inhibition tasks than the No Diagnosis group. No other group comparisons were significant at $p < .01$. When investigating groups differences for the Working Memory domain, the No Diagnosis group performed significantly better than all the diagnostic groups (CT, $p < .001$; PI, $p <$. 001; Other Clinical, p=.001); the ADHD (CT and PI) or Other Clinical groups did not differ from each other on the Working Memory domain score. The standardized mean difference effect sizes were 1.03 (CT), 1.27 (PI) and 0.91 (Other Clinical). On the Planning domain, the CT (p=.007) performed significantly worse than the No Diagnosis. Standardized mean difference effect size was 0.88. No other group differences on planning tasks were indicated.

Using Prorated Scores, No Covariate

To examine differences in Inhibition, Working Memory, Planning, and Attention domain scores, a MANOVA was conducted that included prorated scores for seven participants, increasing the sample size for analyses to 91. The Wilks *lambda F*-test was used to determine significant multivariate effects. The MANOVA was significant for overall effects [F (3, 87)=4.38, $p < .001$]. Post hoc techniques were conducted to identify the direction of group differences for the domain scores that contributed to the multivariate effect. Results are consistent with the previous analysis that did not include the prorated scores (Table 11). Tukey HSD post hoc tests were significant for the Inhibition domain [F (3, 87)=7.46, $p < .001$], the Working Memory domain [F (3, 87)=9.92, $p < .001$], and the Planning domain [F (3, 87)=4.68, p=.004. There were no significant differences between groups for the Attention domain score [F (3, 87)=0.38, p=.77].

For the Inhibition domain, the results were similar to the analysis that did not include prorated scores. Based on both of the analyses, the No Diagnosis group mean was significantly higher than the CT group scores ($p < .001$). No other significant differences were indicated at p < .01. Standardized mean difference effect size was 1.23. On the Working Memory domain, the results are consistent with the initial analysis (i.e., without the prorated scores) with the No Diagnosis group performing significantly better than all the other groups (CT, $p < .001$; PI, $p < .001$; Other Clinical, p=.001).

Standardized mean difference effect size was 1.12 (CT), 1.28 (PI) and 0.92 (Other Clinical). Similarly, the Planning domain results were consistent regardless of the inclusion of prorated scores. The CT (p=.007) group had statistically significant lower scores than did the No Diagnosis group. Standardized mean difference effect size was 0.86.

Table 11

Domains (including prorated scores) by Group

Source	Mean	*SD*	*N*	*F*	*p*
Inhibition	94.30	9.16	91	7.46	>.001
No Diagnosis	99.48	9.00	25		
Combined Type	88.40	7.90	24		
Predom. Inattentive Type	93.29	8.52	14		
Other Clinical	95.24	7.88	28		
Working Memory	92.45	9.94	91	9.92	>.001
No Diagnosis	100.31	10.14	25		
Combined Type	88.92	8.85	24		
Predom. Inattentive Type	87.36	10.73	14		
Other Clinical	91.00	5.62	28		
Planning	94.77	8.70	91	4.68	.004
No Diagnosis	99.92	9.13	25		
Combined Type	92.08	7.60	24		
Predom. Inattentive Type	94.02	8.27	14		
Other Clinical	92.86	7.82	28		
Attention	96.77	10.66	91	.384	.765
No Diagnosis	98.65	12.91	25		
Combined Type	96.44	10.44	24		
Predom. Inattentive Type	96.36	12.46	14		
Other Clinical	95.58	7.62	28		

Note. Predom.=Predominantly

Group Differences with Covariation for IQ

Given that cognitive abilities are often correlated with neuropsychological measures, some researchers suggest statistically controlling for the impact of intellectual differences on tasks (Werry, Elkind, & Reeves, 1987). Other researchers express concerns about partialing out some of the effects of symtomatology when statistically controlling for cognitive differences (Nigg, 2001; Seidman, Biederman, Faraone, Weber, & Ouellette, 1997). The correlation between IQ and ADHD symptomology is reported to be between r =.30 and -.35 (Ardila, Pineda, & Rosselli, 2000; Barkley, 1998). Therefore, in addition to MANOVAs, MANCOVAs with the Full Scale IQ as the covariate were employed. Results of the MANCOVA analysis without prorated scores are presented in Table 12; analysis with prorated scores is presented in Table 13.

The multivariate effect was significant [F (3, 79)=2.98, p=.001]. Univariate tests revealed significant differences for across groups for the Inhibition domain [F (3, 79)=6.24, p=.001], and the Working Memory domain [F (3,79)=4.57, p=.005]. However, comparisons for the Planning domain [F (3,79)=2.65, p =. 054] were not significant. There were no significant groups differences across the Attention domain scores [F (3,79)=0.21, p=.89].

Table 12

Adjusted Means from MANCOVA for Domain Score Differences Across Groups (N=84)

Source	Mean	Std. Error	N	F	p
Inhibition	94.22	.95	84	6.24	.001
No Diagnosis	98.65	1.80	24		
Combined Type	88.02	1.81	21		
Predom. Inattentive Type	95.13	2.47	12		
Other Clinical	95.09	1.63	27		
Working Memory	92.04	.86	84	4.57	.005
No Diagnosis	97.16	1.63	24		
Combined Type	89.10	1.64	21		
Predom. Inattentive Type	89.69	2.23	12		
Other Clinical	92.18	1.48	27		
Planning	95.16	.85	84	2.65	.054
No Diagnosis	97.83	1.61	24		
Combined Type	91.79	1.62	21		
Predom. Inattentive Type	96.61	2.21	12		
Other Clinical	94.40	1.46	27		
Attention	96.56	1.20	84	.208	.890
No Diagnosis	95.69	2.28	24		
Combined Type	95.42	2.29	21		
Predom. Inattentive Type	98.21	3.12	12		
Other Clinical	96.93	2.06	27		

Note. Evaluated at covariate: Full Scale IQ; Predom.=Predominantly

Table 13

Domain Differences with Prorated Scores and IQ as Covariate

Source	Mean	*SD*	*N*	*F*	*p*
Inhibition	94.30	9.16	91	6.82	>.001
No Diagnosis	99.48	9.00	25		
Combined Type	88.40	7.90	24		
Predom. Inattentive Type	93.29	8.52	14		
Other Clinical	95.24	7.88	28		
Working Memory	92.45	9.94	91	5.41	.002
No Diagnosis	100.31	10.14	25		
Combined Type	88.92	8.85	24		
Predom. Inattentive Type	87.36	10.73	14		
Other Clinical	91.00	5.62	28		
Planning	94.77	8.70	91	2.34	.079
No Diagnosis	99.92	9.13	25		
Combined Type	92.08	7.60	24		
Predom. Inattentive Type	94.02	8.27	14		
Other Clinical	92.86	7.82	28		
Attention	96.77	10.66	91	.119	.949
No Diagnosis	98.65	12.91	25		
Combined Type	96.44	10.44	24		
Predom. Inattentive Type	96.36	12.46	14		
Other Clinical	95.58	7.62	28		

Note. Evaluated at covariate: Full Scale IQ; Predom.=Predominantly

Post hoc pairwise comparisons indicated that for the Inhibition domain the No Diagnosis group performed significantly better than CT group ($p < .001$). Standardized effect size was 1.36. No other group differences were indicated on the Inhibition domain score. On the Working Memory Domain, pairwise comparisons indicate that the CT group performed significantly poorer on the selected measures than did the No Diagnosis group (p=.004). Standardized effect size was 1.03. After using an adjusted alpha level of $p < .01$, no other group differences were indicated.

Covariation for IQ and Prorated Scores for Missing Data

The multivariate effect was significant [F (3, 86)=3.21, $p < .001$]. Univariate tests revealed significant differences for across groups for the Inhibition domain F (3, 86)=6.82 $p < .001$] and the Working Memory domain [F (3, 86)=5.41, p=.002]. In contrast to earlier analyses, when including the additional prorated scores and using Full Scale IQ as a covariant, there were no significant differences between groups for the Planning domain [F (3, 86)=2.34, p=.08]; there were no differences across the Attention domain [F (3, 86)=0.12, p=.95].

Post hoc pairwise comparisons indicate that results are consistent with previous analyses for the differences across groups on the Inhibition domain. The No Diagnosis group scores were significantly higher than the CT ($p < .001$). Standardized effect size was 1.23. No other differences between groups for the Inhibition domain scores were indicated after including prorated scores or covary for IQ effects. Results for group differences across the Working Memory domain appear to vary when the effects for IQ are analyzed. The No Diagnosis group demonstrated significantly higher scores on the Working Memory domain scores than the CT group (p=.001). Standardized effect size was 1.12. A summary of differences by analysis is presented in Table 14.

Summary of Group Differences across Domain Scores

The following table summarizes differences in results for group differences for the four different analyses conducted (Table 14).

Table 14

Summary of Results by Analysis for Theoretically Derived Domains

(*N*=84)	Prorated (*N*=91)	IQ as Covariate (*N*=84)	IQ as Covariate and Prorated (*N*=91)
		Inhibition	
No Diagnosis > CT	No Diagnosis > CT	No Diagnosis > CT	No Diagnosis > CT
		Working Memory	
No Diagnosis > CT, PI, Other Clinical	No Diagnosis > CT, PI, Other Clinical	No Diagnosis > CT	No Diagnosis > CT
		Planning	
No Diagnosis > CT	No Diagnosis > CT	No Significant Differences	No Significant Differences
		Attention	
No Significant Differences	No Significant Differences	No Significant Differences	No Significant Differences

Analyses were conducted with prorated scores to reduce missing data and without those scores as well as with covarying for effects of IQ across groups. Including prorated scores did not significantly effect the outcomes for analyses conducted. Results for group differences were identical with regard to significant findings at $p < .01$. However, covarying for the effects of IQ on domain scores did effect results when examining group differences. For the Inhibition and Attention domains, the results were consistent for group differences across domain scores. For the Working Memory and planning domains, some differences between groups were no longer significant after controlling for the effects of IQ. Specifically on the Working Memory domains, the No Diagnosis performed significantly better then the CT groups after controlling for IQ effects, but the No Diagnosis group no longer performed significantly better than the PI and Other Clinical groups. For Planning, the better performance of the No Diagnosis group did remain after controlling for IQ effects.

Variance Accounted for by Domain Scores

To examine which domain accounted the greatest between group variance (ADHD-CT, ADHD-PI, Other Clinical, and No Diagnosis) a multiple discriminant analysis with stepwise estimation (Malahanobis distance) was conducted (Research Question 3). Data screening, statistical analyses, and reporting were conducted as much as possible as recommended by Huberty and Hussein (2003). Huberty and Hussein (2003) suggested that either the researcher conduct a predictive or descriptive discriminant analyses based on the research question of interest. A predictive discriminant analysis was conducted using SPSS 11.0. The predictor or independent variables were the executive processes of interest (inhibition, working memory, planning, and attention) as measured by the domain scores described earlier. A minimum ratio of 5 cases per variable with a recommended ratio of 20 cases per variable is suggested for discriminant analysis (Hair et al., 1995). Missing values were replaced with the mean. With an available overall sample size of 91, the overall sample is adequate for the analysis. The minimum group size preferred is at least 20 cases. One group (ADHD-Predominantly Inattentive Type) had fewer than the recommended cases with n=14; however, this is close to the recommended group size and results will be interpreted with caution. The independent variables adequately met assumptions of normality, linearity, and collinearity as discussed earlier. The Box's *M* test indicates that the hypothesis of equal population covariances is not rejected ($p = .21$). In other words, the data meet the assumption of equal population covariance matrices or dispersion.

The Wilks' Lambda test, which tested functions for statistical significance, in the stepwise analysis identified one discriminant function that was significant ($\chi^2 = 40.10$; $p < .001$). However, the stepwise method of variable selection did not identify any of the executive functions of interest (Inhibition, Planning, Working Memory, and Attention) as significant predictors of group membership (ADHD [CT or PI], No Diagnosis, or Other Clinical groups; see Table 15). Since none of the predictors significantly contributed to group membership, no other results of the predictive discriminant analysis were interpreted.

Table 15

Discriminant Analysis

		Minimum D Squared					
				Exact F			
Step	Entered	Statistic	Between Groups	Statistic	df1	df2	Sig.
1	Inhibit	.06	Other Clinical & Predom. Inattentive	.52	1	87	.48
2	Working Memory	.21	Other Clinical & Predom. Inattentive	.98	2	86	.38

Note. Maximum number of steps=8; Maximum significance of F to enter=.05; Minimum significance of F to remove=.10.

Supplemental Analyses

Further Evaluation of the Theoretical Model

Given the correlational and discriminant analysis results (Table 9 and Appendix B), there was some concern that, despite the theoretical basis to the construction of the domain scores, other combinations of the 16 variables might result in a better measurement model. A measurement model is comprised of the indicator or observed variables and the underlying latent variables for constructs that the observed variables are proposed to measure. Latent variables are typically hypothetical constructs that in this study include the four domains of interest: Inhibition, Working Memory, Planning, and Attention. To evaluate the extent to which the observed variables would produce an acceptable representation of the domains of interest, a confirmatory factor analysis was conducted.

For this study, the requirements for sample size and data characteristics were of concern. Recommendations for sample size based on Monte Carlo studies are such that absolute sample sizes less than 100 are not advised because of effects on statistical stability (Ding, Velicer, & Harlow, 1995; Kline, 1998); however, others indicate that an absolute sample size minimum is 50 (Hair, Anderson, Tatham, & Black, 1995). Several rules of thumb have been used for sample size requirements. A ratio of 10 to 20 to 1 for subjects to free parameters is recommended for CFA by Kline (1998). Bentler and Chou (1987) suggested that a ratio as low as five subjects per variable would be sufficient for normal distributions when the latent variables have multiple indicators. Another rule of thumb is that three indicators are recommended per latent variable with small samples (Kline, 1998). Potential sample size effects will be discussed further in Chapter V.

Model Testing

The 16 variables that comprised the four domain scores were entered for the CFA. LISREL 8.54 was used to perform analyses (Jöreskog & Sörbom, 2003). Maximum likelihood estimates were derived from covariance matrices. As with other types of analyses, violations of assumptions needed for structural equation modeling (SEM) techniques can result in difficulties with analyses. Therefore, data were screened as suggested by Kline (1998) as previously described.

Next missing data were addressed. Given the small available sample size (n=84) that is at or below the recommended smallest sample size suggested for analysis with SEM, procedures were employed to prevent loss of data due to missing data points (Kline, 1998). Domain scores were prorated for earlier analyses; however, this procedure did not address missing data in the original 16 observed variables. With regard to missing data, 5% to 10% missing data per variable are not considered large (Cohen & Cohen, (1983) as cited by Kline, 1998). The percentage of missing data across the variables ranged from no missing data to a high of 5.38%, which is well within the accepted parameters for SEM techniques. Missing values were substituted with the mean of the variable across groups resulting in a sample of N=93.

Fit indices are tools used to assess model fit, model comparison, and model parsimony (Hair et al., 1995). The Chi-square statistic is the most common fit index that measures the "badness of fit" when comparing the model with the saturated model (Curran, West, & Finch, 1996; Hair et al., 1995). However, it should be noted that the chi-square statistic is biased in small samples and may reject a true model in error (Curran et al., 1996). Therefore, other indices should be examined as well. Chi-square values divided by the degrees of freedom is often used by researchers to control for effects of large samples. The χ^2/df should be less than 2.5 for small samples (Kline, 1998). RMSEA is a measure of difference between estimates for the model fitted to the sample and the model fitted to the population covariance matrix. A RMSEA of <.05 suggests a good fit (MacCaluum, Browne, & Sugawara, 1996). GFI and CFI indices compare the model to the null model. CFI adjusts for model complexity (Kline, 1998). A CFI and GFI value above .90 is recommended to accept a model and the CFI is preferable when sample size is small (Hu & Bentler, 1998). The AGFI is adjusted for model complexity.

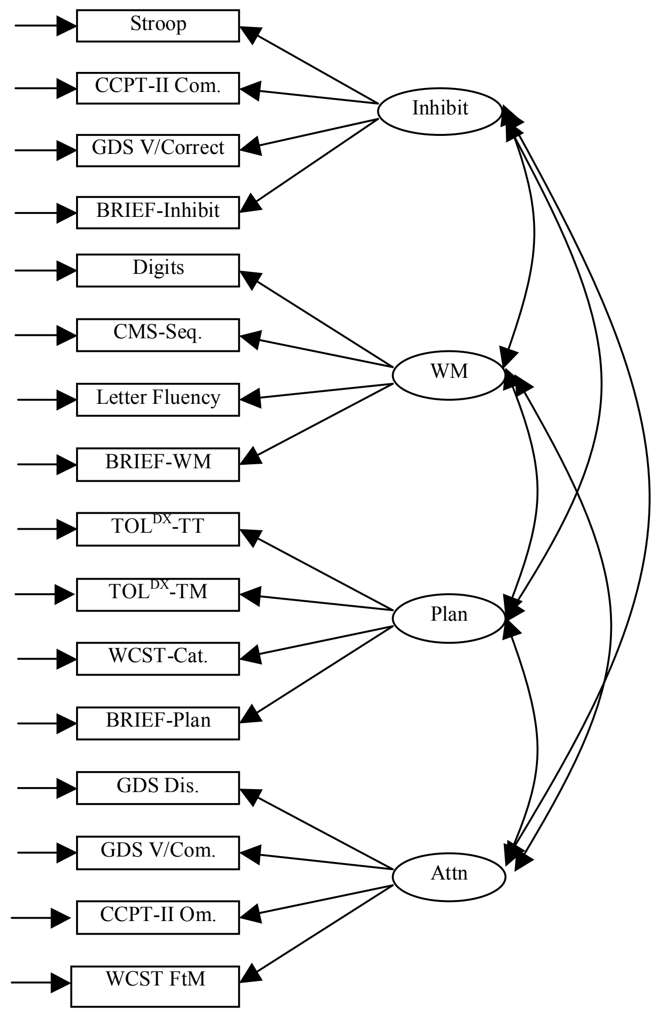

Figure 3 Theoretically Derived Model

Each of the four latent variables (Inhibition, Working Memory, Planning, and Attention) was evaluated with four indicators as proposed. The full, four-factor model assumes some degree of separabilty among all four latent variables. The conceptual model is illustrated in Figure 3. The theoretically derived model (Model 1) yielded a significant chi-square [χ^2 (98, N=93)=12,197.84, (p=0.00), a very large normed Chi-square value [χ^2/df =124.47], RMSEA=1.16 (1.14-1.18), and PCLOSE=.00 (see

Table 16). A Heywood case was indicated. Negative error variance (Heywood cases) refers to an improper CFA solution when the estimated correlation between the indicator and its factor is greater than 1 (Schumacker & Lomax, 2004). These errors can occur because of misspecification in the model, outliers, small samples sizes with only two indicators on a latent variable, or very high or low population correlations (Kline, 1998; Schumacker & Lomax, 2004).

Revisions and eliminations were made based on indicators of misspecified variables such as negative error variance and inappropriate correlation and modification indices. The modification indices suggested adding a path from GDS vigilance commission errors to the latent variable Attention. Other modifications involved the addition of error covariance correlations. Tomarken and Waller (2003) recommended that all post hoc modifications be clearly stated (see Table 16) as such and that if correlated errors terms are added, they should make theoretical sense; other limitations of using correlated error terms should be disclosed.

Table 16

Confirmatory Factor Analyses

Model	χ^2	χ^2/df	GFI	AGFI	RMSEA	PCLOSE	CFI	EVCI
1	12,197.80	124.47	--	--	1.16	0.00	--	--
2	206.50	2.24	.79	.70	.11	0.00	.68	3.00

Model 2 also indicated one variable with negative error variance (Heywood case). Although the chi-square decreased, a lack of fit was indicated (see. Table 16). The theoretically derived model was rejected.

Exploratory Factor Analyses

Given the lack of fit of the theoretically derived model, exploratory factor analyses were conducted in order to investigate the loading and characteristics of the 16 variables. In EFA analyses, maximum likelihood estimates were applied. Given the theoretical nature of executive function constructs, factors were expected to be related to one another and oblique (varimax) rotation methods were utilized. The 16 variables were entered into PRELIS for the analysis (Jöreskog & Sörbom, 2003). For interpretation, at least two measures had to load significantly to form a factor, and complex items were considered. Salient loadings were those $\geq |.40|$ and the highest loading for that variable (Gorsuch, 1997). The Chi-square test is a "badness of fit" test and significance indicates a lack of fit. Modifications were made incrementally and summarized in Table 17.

Table 17

Exploratory Factor Analyses and Goodness of Fit

	Variable(s) excluded	Factors	Heywood	χ^2	χ^2/df	RMSEA
1	None	4*	1	not reported		
2	None	6	2	46.32	1.45	.045
3	BRIEF scales	6	3	15.26	1.02	.014
4	BRIEF scales & GDS V/Com.	4	0	29.40	1.23	.049
5	BRIEF scales & GDS V/Com.	3*	0	46.82	1.42	--
6	BRIEF scales, GDS V/Com., & GDS V/Correct	4	1	17.96	1.06	.025

Note. * Analysis constrained; GDS V/Correct=GDS Vigilance Correct; GDS V/Com.=GDS Vigilance Commission errors; BRIEF scales=BRIEF Plan/Organize, BRIEF Working Memory, and BRIEF Inhibition; Heywood cases for EFA 1=CCPT-II Commission errors; EFA 2=CCPT-II Commission errors & GDS Vigilance Commission errors; EFA 3=CCPT-II Commission errors, GDS Vigilance Commission errors, & TOL^{DX}-Total Time; EFA 6=CCPT-II Omissions.

Six analyses were conducted in order to attempt to identify an admissible factor structure with the variables of interest. Each of the six factor structures and unique variances are reported in Appendix C. A four-factor (constrained) analysis of the 16 variables was unintrepretable due to one variable that had negative error variance (Heywood case). The Chi-square test of goodness of fit and RMSEA was not reported in the output. An unconstrained analysis yielded a six-factor solution; however, two variables had negative error variance (Heywood cases). As noted earlier, Heywood cases have to be addressed before fit can be reliably interpreted (Kline, 1998; Schumacker & Lomax, 2004). For example, as reported in Table 17, the fit indices for this analysis are within acceptable limits but they are unreliable. Examination of these results indicated that the BRIEF (Working Memory, Inhibition, and Planning/Organization Scales) parent report measures all loaded on a single factor. As such, they were excluded. In effect, they formed a factor of parent report as opposed to loading with any of the laboratory measures. This is not an uncommon finding with other rating scales and laboratory measures (Matier-Sharman, Perachio, Newcorn, Sharma, & Halperin, 1995; Price, Joschko, & Kerns, 2003; Sbordone, 1997; Vriezen & Pigott, 2002).

An unconstrained analysis, after the elimination of the BRIEF scales, produced a six-factor solution (Table 17). The Chi-square was significant [χ^2 (15, N=93)=15.26, (p=.43)]. The analysis indicated three Heywood cases. One of the offending variables (GDS Vigilance commissions errors) was removed from the analysis to attempt to address Heywood cases. After removing one offending variable, a four-factor solution was obtained. The chi-square was nonsignificant indicating a fit [χ^2 (24, N=93)=29.40, (p=.21). A small normed Chi-square value [χ^2/df =1.23] and RMSEA=.049 (see Table 18) are also suggestive of an adequate model fit. No Heywood cases were present. The Varimax rotated four-factor solution is presented in Table 17. A three-factor solution was explored for the 12 variables. The chi-square and normed chi-square increased [χ^2 (33, N=93)=46.82, (p=.21);]χ^2/df =1.42]. The RMSEA was not provided in the output. The four-factor solution appears to indicate a better fit with the 12 variables. Given the interest in the four factors in this study, the four-factor solution was retained. The variable (GDS Vigilance correct=.36) with smallest absolute factor loading across the factors was removed. The unconstrained analyses revealed a four-factor solution with a Heywood case (Table 17). Thus, this solution was not pursued further.

The following factor analysis provided an adequate factor structure that makes theoretical sense (Table 18).

Table 18

Four-Factor solution with 12 Variables

	Factors				
Measures	1	2	3	4	Unique Variance
CCPT-II Om.	.78	.14	.06	-.18	.34
CCPT-II Com.	.44	-.10	.02	.16	.77
GDS V/Correct	.36	.06	-.32	-.18	.74
CMS-Seq.	-.02	.72	-.23	-.04	.43
Stroop	.19	.52	.14	.02	.67
Letter Fluency	-.02	.46	-.13	-.27	.70
Digits Backward	-.05	.38	-.22	.01	.80
TOL^{DX}-TT	-.08	.10	-.60	-.09	.61
TOL^{DX}-TM	.03	.12	-.44	-.02	.80
GDS Dist.	.38	.10	-.40	-.22	.64
WCST-Cat.	.12	>.01	-.19	-.72	.44
WCST-FtM	-.19	.35	.41	-.43	.48

Note. WCST-FtM=WCST Failure to maintain set; GDS V/Correct=GDS vigilance correct; GDS V/Com.=GDS vigilance commission errors; WSCT-Cat.=WCST Categories obtained; CMS-Seq.=CMS sequences subtest; FAS=Letter Fluency; Digits=WISC-III Digits backward; Stroop=Stroop Color-Word score; TOL^{DX}–TT=Tower of $London^{DX}$ Total time; TOL^{DX}– TM=Tower of $London^{DX}$ Total moves; CCPT-II Com.= CCPT-II commission errors; CCPT-II Om.=CCPT-II omission errors

There continued to be complex measures that loaded across factors; however, in most of the configurations, there was a strong factor that appeared to be comprised of measures thought to tap working memory skills. The other three factors appeared to have measures of attention, inhibition, and planning.

Model Generation

Following the EFA procedures, confirmatory factor analyses were conducted. It is highly recommended that researchers use separate samples in order to examine model fit following exploratory factor analysis. However, given the sample size, it is not feasible in this study. To approximate the results, "Leave one out" was utilized. The twelve variables with four latent variables were entered into LISREL 8.54 (Jöreskog & Sörbom, 2003). Maximum likelihood estimates were derived from covariance matrices. The EFA-based (Model 3) yielded a significant chi-square [χ^2 (48, N=93)=9,131.62, (p=0.00), and a very large normed Chi-square value [χ^2/df =190.24], and RMSEA=1.43 1.41-1.46), PCLOSE=.00. However, no Heywood cases were indicated.

One modification was indicated for the error covariances. When allowing the two error covariances to correlate the model improved significantly; however, a Heywood case was indicated. Correlated error terms suggested that there is common variance between the indicators that is not accounted for by the model. While measures from the same instrument would be expected to be correlated, allowing errors to be correlated also could improve model fit statistically, but not necessarily improve theoretical fit or interpretation. If possible, a more parsimonious model, with no correlation of error terms, is desired. One observed variable was removed from the model because it accounted for a very small portion of variance (WCST- failure to maintain set = .99 error covariance). After removing the observed variable, a model with an adequate approximation was identified (Figure 4). However, the correlation between two latent variables was very high (.94) and one path was not significant. The EFA-based (Model 5) yielded a nonsignificant chi-square [χ^2 (38, N=93)=46.49, (p=.16), and a small normed Chi-square value [χ^2/df =.51], and RMSEA=.044 (0.0 -.089), PCLOSE=.55. The nonsignificant path was deleted resulting in a model with a correlation matrix containing an improper value (Model 6). The very high correlation between the Attention and Inhibition latent variables was 1.09 indicating that the model was misspecified.

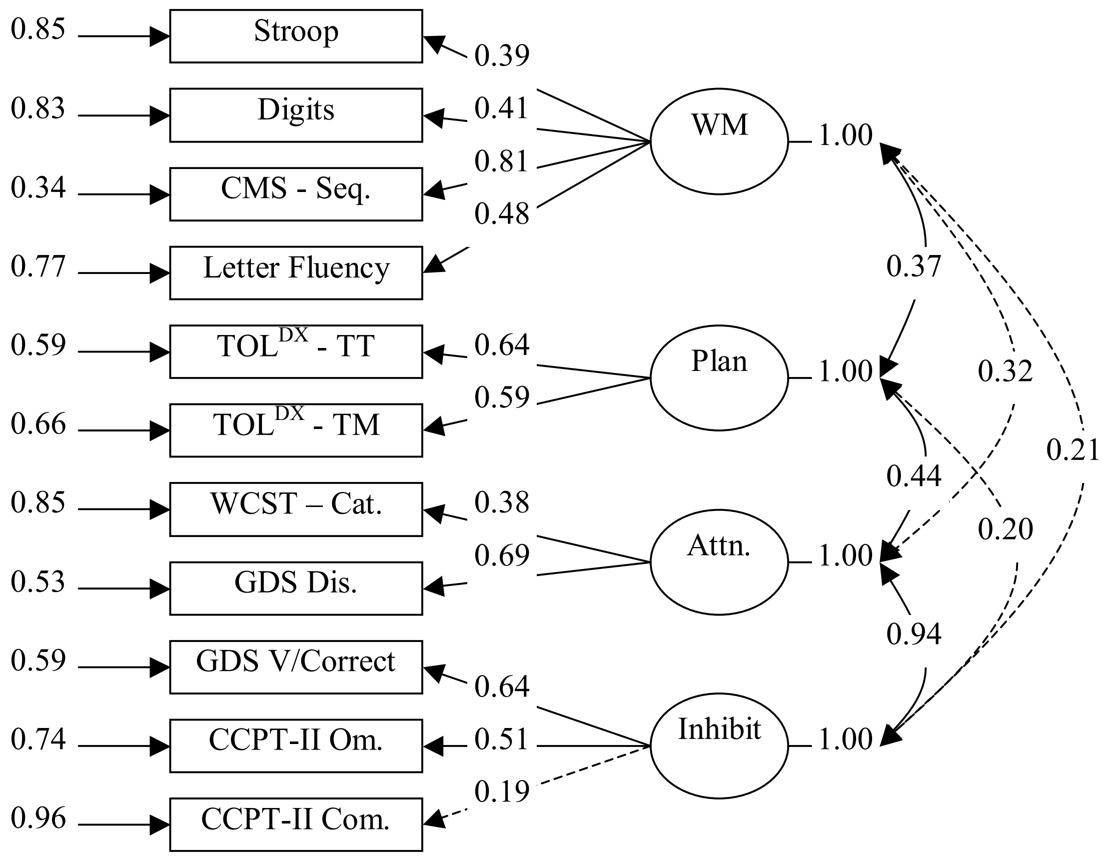

Figure 4 Model Based on EFA Results

For Figure 4 and Figure 5, the single headed arrows (←) have loadings that are standardized regression coefficients. Squared errors terms, that give estimates of variance not accounted for, are at the end of single headed arrows (→). The curved double-headed arrows have correlation coefficients. Dashed lines represent relationships that are not significant (*p*< .05).

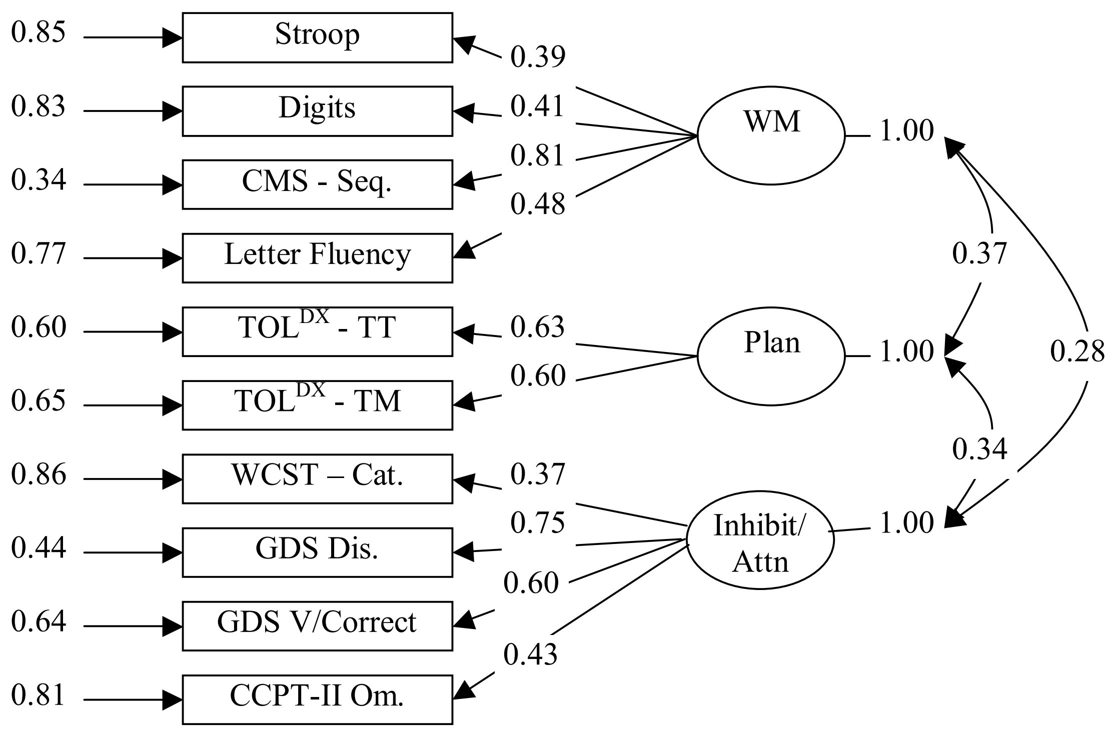

Figure 5 Best Fit Model

Given this result, the two latent variables (Attention and Inhibition) were combined. As can be seen from Table 19, this model did provide a better fit to the data than the modified theoretical model (Model 2) or the admissible solution with four latent variables (Model 5). The revised model with three latent variables (Model 7) yielded a nonsignificant chi-square [χ^2 (32, *N*=93)=25.72, (*p*=.78), a small normed Chi-square value [χ^2/df =.80], RMSEA=.0 (0.0 -.093), and PCLOSE=.94 (see Table 20). Another consideration when examining model fit is the correlation residuals or standardized residual matrix. The residual matrix is the difference between the observed covariance and the reproduced covariance matrix (Shumaker & Lomax, 2004). Similar to z-scores, large standardized residuals values (>1.96 or 2.58) indicate that a particular relationship is not well represented in the model. The largest standardized residual was |1.95| which indicates a good fit.

Table 19

Confirmatory Factor Analyses and Goodness of Fit

Model	χ^2	χ^2/df	GFI	AGFI	RMSEA	PCLOSE	CFI	EVCI
1	12,197.80	124.47	--	--	1.16	0.00	--	--
2	206.50	2.24	.79	.70	.11	0.00	.68	3.00
3	9131.6	190.24	--	--	1.43	0.00	--	--
4	62.36	.68	.90	.84	.052	.45	.88	1.31
5	46.49	.51	.92	.86	.044	.55	.93	1.09
6	24.97	.86	.95	.90	0.00	.89	1.00	.88
7	25.72	.80	.95	.91	0.00	.94	1.00	.85

Note. Model 1=Theoretical model; Model 2=Revised model; Model 3=Model based on EFA with 12 variables; Model 4=Model based on EFA with 12 variables with correlated error terms; Model 5=Model based on EFA with 11 variables; Model 6=Model based on EFA with 10 variables (nonpositive definite correlation matrix); Model 7=Three latent variables with 10 observed variables.

Group Differences with Improved Model

For consistency, procedures for examining group differences across the revised domains (Attention/Inhibition, Working Memory, and Planning) were similar to those used when examining group differences on the theoretically derived model; however, prorated domain scores were not calculated.

Table 20

Descriptives of Revised Domains

Measures	*N*	Mean	*SD*	Skewness	Kurtosis
Working Memory	90	95.63	9.58	.17	.04
Planning	93	97.78	11.93	-.75	.56
Attention/Inhibition	89	96.71	12.09	-.70	-.42

A 4 group (CT, PI, Other Clinical, and No Diagnosis) X 3 domain (Attention/Inhibition, Working Memory, and Planning) MANOVA was conducted using only those participants with all 10 variables (N=86; see Table 20). As noted earlier, the alpha was set at $p < .01$ to decrease the likelihood of finding a difference when none exists (Type I error). The Wilks *lambda* F-test was used to determine significant multivariate effects. The MANOVA was not significant for overall effects [F (3,82)=.886, $p = .54$]. No differences between groups were indicated on the revised domains (Table 21). Implications and conclusions of the results reported in this chapter will be discussed in Chapter V.

Table 21

Revised Domains by Group

Source	Mean	*SD*	*N*	*F*	*p*
Inhibition/Attention	96.60	12.26	86	.127	.944
No Diagnosis	97.75	14.49	25		
Combined Type	95.97	12.94	21		
Predom. Inattentive Type	97.00	11.67	13		
Other Clinical	95.84	10.19	27		
Working Memory	95.85	9.58	86	2.54	.062
No Diagnosis	100.04	11.11	25		
Combined Type	94.56	9.19	21		
Predom. Inattentive Type	92.47	10.66	13		
Other Clinical	94.62	6.54	27		
Planning	98.50	11.51	86	.036	.991
No Diagnosis	98.42	12.23	25		
Combined Type	97.93	12.25	21		
Predom. Inattentive Type	99.23	11.03	13		
Other Clinical	98.67	11.10	27		

Note. Predom.=Predominantly

CHAPTER V

SUMMARY AND DISCUSSION

The purpose of this study was to examine the roles of executive functions, specifically; inhibition, attention, working memory, and planning in youth with and without ADHD. Current theories reviewed conceptualize the behavioral symptoms of ADHD as manifesting from those mental processes. Examining these opposing and sometimes complementary theories of ADHD can aid in supporting the theories. Developing or refining theories that explain the behavioral manifestation of ADHD can help clinicians with improved diagnoses and particularly differential diagnoses and with the designing and implementation of interventions. Research that assists in identifying or supporting a particular executive process as underlying the behaviors of ADHD as proposed by Barkley (1997) and Rapport et al. (2001) may help our understanding of ADHD. When considering children with ADHD, researchers have proposed impaired inhibition as the underlying deficit affecting executive function processes (Barkley, 1997; Quay, 1997). Barkley (1997) proposed disinhibition as the primary deficit of ADHD; disinhibition then contributes to difficulties in working memory and executive functions. In contrast, Pennington (1994) and Rapport, Chung, Shore, & Isaacs, (2001) argued for working memory as being primary and contributing to deficits in executive function and inhibition processes. Although there are some contradictions in the models, there are also elements that are complementary. Mirsky (1987) proposed a four factor model of attention such that children and adolescents with ADHD have deficits in three out of the four factors. Fernandez-Duque and Posner (2001) proposed that attention is comprised of three systems; Orienting Attentional System, Executive Attentional System, and Vigilance Attentional System. Of these, Posner proposed that ADHD is a disruption of the Vigilance Attentional System (1990).

This study examined the differences in inhibition, attention, working memory, and planning processes to investigate the interplay and contribution of those executive processes in children with ADHD. Measures of inhibition, attention, working memory, and planning were selected based on a literature review of factor analytic and latent variable analyses. Based on current literature, it was predicted that the youth with ADHD would perform poorer on measures of inhibition, attention, working memory, and planning than children with no diagnosis (Research Question 1). Additionally, children with ADHD were expected to differ on one or more of the processes under investigation from children with other clinical diagnoses (Research Question 2).

Group Differences

When initially examining the domains that were formed based on a literature review of factor analytic studies, the research questions 1 and 2 were partially supported. However, there were some significant measurement issues that will be discussed in further detail. Children and youth with ADHD-Combined Type performed poorer on theoretically derived measures of inhibition than children with no diagnosis. The role of IQ on executive function measures also was examined; this difference in performance on measures purported to tap inhibition persisted after statistically controlling for effects of IQ. This result is consistent with Barkley's (1997) model of ADHD in that children with ADHD-Combined Type have disordered inhibition. Some previous studies have found moderate to large effect sizes on inhibition measures in ADHD (Berlin, Bohlin, Nyberg, Janols, 2004; Pennington & Ozonoff, 1996; Rapport, Van Voorhis, Tzelepis, & Friedman, 2001; Stevens, Quittner, Zuckerman, & Moore, 2002). In some studies that have controlled for group differences in IQ, the magnitudes between groups on neuropsychological tasks have decreased (Murphy, Barkley, & Bush, 2001; Scheres et al., 2004). This study contradicts the findings of Scheres et al. (2004) that found differences between groups on inhibition that did not survive the removal of IQ effects.

When considering measures originally selected to tap working memory, children with ADHD-Combined Type, ADHD-Predominantly Inattentive Type, and other diagnosis performed poorer than children with no diagnosis. However, after statistically controlling for effects of IQ, the children with no diagnosis outperformed children with ADHD-Combined Type; no other differences remained. Poorer performance on tasks purported to measure working memory by children with ADHD is consistent with other studies (Mariani & Barkley, 1997; Stephens et al., 2002). Scheres et al. (2004) found that group differences between children with ADHD and normal controls on measures of working memory did not remain after controlling for effects of IQ. In another similar study, when IQ effects were controlled, the group differences were attenuated as well (Tripp et al., 2001). With the measures initially selected based on a literature review, the difference between children with no diagnosis and those with ADHD-Combined Type remained even after partialing out IQ effects.

On measures selected to tap planning abilities, children with ADHD-Combined Type evidenced poorer planning than children with no diagnosis. Differences in planning abilities between children with no diagnosis and those with ADHD-Combined Type were attenuated when IQ was controlled. Previous research indicated that differences in planning abilities between children with ADHD and those without ADHD have been equivocal. As noted earlier, few studies have controlled for IQ and examined difference between subtypes in ADHD.

When considering attention, a process that was once thought to be a hallmark of ADHD, there were no differences between the children on measures. This is consistent with a study that found no differences between ADHD subtypes on measures of abilities to focus and sustain attention (Lockwood, Marcotte, & Stern, 2001). Thus, children with ADHD did not evidence poorer attention or planning after controlling for IQ effects.

Variance Accounted for by the Theoretically Derived Domains

The last research question proposed was to investigate which of the components of executive function selected for this study accounted for the greatest variance in the presence of ADHD (Research Question 3). A predictive discriminant analysis was conducted. One significant function was identified; however, none of the executive processes of interest significantly predicted group membership. This attempted to determine whether attention, working memory, or inhibition was a primary deficit in children with ADHD. Given that executive function deficits are found in a variety of disorders, examining the primary deficit in ADHD would be helpful for differential diagnosis and for designing interventions. In this sample, children with ADHD-Combined Type performed poorer on measures purported to tap working memory and inhibition. However, when a predictive discriminant analysis was conducted, no significant predictors between groups were indicated. Thus, it could not be determined which domain contributed the most to group membership.

Measurement Issues

The correlational and predictive discriminant analysis indicated that despite careful selection of measures to include in the domains, other combinations of the 16 variables might result in a better measurement model. Therefore, before interpreting group differences on domain scores and discussing implications, measurement issues need to be considered. Although there have been recent improvements in assessment procedures and measures, there are still significant measurement issues. Researchers attribute the differing processes to the same tools, which certainly complicate the identification of primary deficits associated with ADHD. Given the complexity of neuropsychological measures and the multi-component nature of executive processes, further evaluation of the theoretical model was explored.

For example in this study, the correlations between subtests and domain scores indicated that several of the measures may not be contributing to the domains as hypothesized. The WCST failure to maintain set score had larger correlations with the working memory domain than it did on the domain in which it placed (Attention). However, both correlations were of a small magnitude indicating that the measure did not have a strong relationship with either domain. In addition, the parent ratings of executive function (BRIEF Working Memory, Inhibit, and Plan/Organize subscales) all had significant correlations with three domains (Inhibition, Working Memory, and

Planning). This may suggest that these measures are not as closely related to the laboratory measures of those processes and may tap multiple executive processes.

First, a confirmatory factor analysis was conducted to investigate the theoretically derived model. It should be noted that there were some significant limitations with these analyses including a small sample size that will be discussed later. The theoretically derived model did not fit the data. In fact, it was a very poor representation with a large chi-square value and Heywood cases. As noted earlier, Heywood cases or negative error variance refers to an improper solution and can indicate other difficulties with the analysis (Schumacker & Lomax, 2004). Following revisions to the theoretically derived model based on the modification indices, there was still a lack of fit indicating that the model is not a good representation. The lack of fit of the theoretically derived model suggests that there may be a better combination of the 16 variables selected to reflect or comprise the executive processes included in this study.

Exploratory factory analysis indicated that parent ratings of different executive processes on the BRIEF scale were loading on a single factor rather than with any of the laboratory measures that were purported to tap the same executive processes. This is consistent with the correlational analysis. As noted earlier, this is not an uncommon finding with other rating scales and neuropsychological measures (Matier-Sharman, et al., 1995; Price et al., 2003; Sbordone, 1997; Vriezen & Pigott, 2002). Several other exploratory analyses could not be interpreted due to Heywood cases. An admissible four-factor solution retaining 12 of the original 16 variables was identified. Following the exclusion of the BRIEF scales, the GDS Vigilance Commission errors score was excluded due to negative error variance (Heywood case).

After testing the original model and identifying through exploratory analyses an admissible fit, the model was evaluated with CFA procedures. It is highly suggested that researchers use split or separate samples when examining model fit following exploratory procedures. However, given the small sample size and the average length of the evaluations (nine hours per child); this was not feasible. To approximate the results, “leave one out” was used. The initial model based on EFA procedures did not represent an adequate fit; however, no Heywood cases were indicated. Following the removal of one indicator variable that was contributing very little to the analysis, an adequate model fit was identified (Figure 5). The latent variables of interest were correlated with one another as would be expected given that they were conceptualized as falling under the umbrella of executive function; however, the measures thought to tap attention and inhibition were very closely related (r=.94) in this sample. This result raises the question as to whether or not the two constructs should be considered separable or measuring the same thing. In addition, the portions of unexplained variance of some of the indicator variables were quite high. The two latent variables (Attention and Inhibition) were combined resulting in a model that was a better representation of the data (Figure 6). With the measures selected for this study, Attention and Inhibition were not separable.

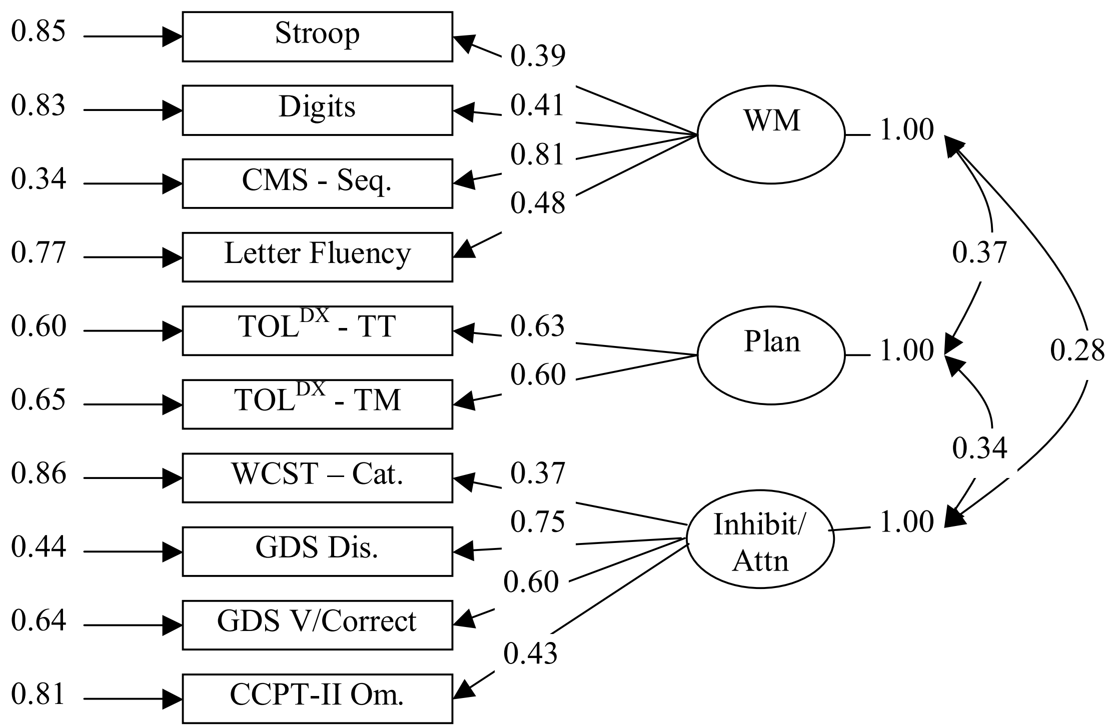

Figure 6 Revised Model

Taken together, the results indicated that the measures selected to tap executive function in children may not be clean measures of inhibition, working memory, planning, or attention processes. With the goal of trying to identify primary or underlying processes involved in the behavioral manifestation of ADHD, this study was unable to clearly identify those processes. The executive processes of inhibition, working memory, planning, and attention, as currently operationalized may be too broadly defined therefore lacking specificity. Not only may the measures selected lack specificity for the domains, but as noted earlier there is significant overlap in the conceptualization of those processes in the theories reviewed in this study. The model indicated that attention and inhibition as conceptualized and measured in this study were not separable. After combining Attention and Inhibition measures and eliminating a indicator variable, an acceptable model was identified. This model indicated that with the remaining 10 measures, three latent variables adequately accounted for the variance in the measures.

Implications for Research and Practice

After revising the domains, there were no differences indicated between groups on attention/inhibition, working memory or planning. Given that there were no significant group differences across the measures used in this study to tap working memory, attention/inhibition, and planning there is no support for any of the theories reviewed in this study. More research is needed with other measures thought to tap executive processes that are indicated by theories as being possible primary or underlying causes of the behavioral manifestation of ADHD. As findings in the area of executive function and ADHD have been equivocal, the need to use methods such as latent variable analysis to explore measures in order to identify cleaner measures of these processes is also needed.

The results lead one to question whether or not the measures selected for this study and others are adequate for the purpose of measuring discrete executive processes. As conceptualized, executive function is a multi-component, umbrella term that is comprised of processes that have also been conceptualized as multi-component in nature. Given the complex nature of executive function or higher order processing, it is reliant on other nonexecutive processes such as language or visuospatial processing.

Therefore, task specificity may greatly effect scores on executive function measures (Miyake et al., 2000).

In addition, to task specificity, there is a lack of strong evidence regarding what many executive function tasks measure (Miyake et al., 2000). Measures were selected based on a careful literature review of studies of children with ADHD to determine which measures tap inhibition, working memory, planning and attention. However, several of the measures were not found to be tapping the processes as proposed in the theoretical model. Without the use of latent variable analyses to examine the underlying structure of the measures selected, different conclusions would have been reached regarding group differences and the implications for practice and science. However, the finding that the measures selected are not clean measures and may not measure the processes as originally proposed is an important one. In the long term, the increased use of latent variables analyses may help minimize the task specificity problem (Miyake et al., 2000).

Other measures should be investigated to determine their contribution to our understanding of executive functions and the relationship they have with ADHD. As discussed in the literature review, many of the measures selected were originally designed for use with adults and were then extended for use with children. Perhaps other measures not selected for this study would better tap executive processes.

In addition to considering task specificity and measurement validity, in general, groups of children with ADHD can be very heterogeneous (Landau & Burcham, 1995). The heterogeneous nature of ADHD could significantly impact the ability to detect group differences. The impact of comorbid disorders was not considered which can contribute to group heterogeneity as well.

It was a goal of this study to investigate the interplay of specific executive processes; the measures selected do not appear to be clean measures of the processes under study. Clinically, these findings emphasize the importance of using multiple assessment methods, multiple reporters of behaviors, in multiple settings for diagnosis of ADHD and not relying on laboratory measures. Direct observations of the child in multiple settings, interviews and/or behavioral ratings scales from parents or guardians as well as school personnel are important in the identification of attention difficulties. Ruling out other disorders that can contribute to attentional difficulties is also recommended (American Academy of Pediatrics, 2000; Landau & Burcham, 1995). A neurodevelopment screening may be needed to rule out medical conditions that can contribute to attention problems. The impact of speech and language development should also be considered. In addition to using best practice recommendations currently in place for both physicians and psychologists for diagnostic purposes, in the school setting, a psychologist maybe better served in assisting the child and teachers by thinking in terms of specific problem identification and intervention planning (Landau, & Burchman, 1995). Therefore focusing on the specific problems experienced by the child in school and at home in order to design and implement interventions would be helpful.

With regard to using the laboratory measures under investigation, there are some significant differences between examining and considering group data and the neuropsychological evaluation of an individual child. For example, when conducting an evaluation of an individual, a clinician considers the individual's performance across measures looking for patterns of performance to identify strengths and weaknesses. Given that the measures selected do not appear to be clean measures of a specific process, the clinician needs to consider the multiple processes that are tapped by tasks when examining score patterns. Latent variable studies such as this one may help identify underlying processes that are in executive tasks. For example, a child may have a poor performance on a purported measure of auditory attention, however; the complex rules of the tasks may have interfered with the child's ability to perform because of difficulties with the working memory and/or inhibition requirements. The lower score may be more reflective of a working memory or inhibition problem rather than difficulties with the auditory attention component. In this case, comparing the child's performance on a more simple auditory attention measure as well as other tasks that tap working memory and inhibition may aid the clinician in further identification of specific strengths or weaknesses. Until further research is conducted on other newly developed batteries used to assess children's executive processes, examining patterns of scores may be helpful in identifying strengths and weaknesses. Clinicians should continue to follow research in order to stay abreast of new developments in our understanding of executive processes in children.

For example, the BRIEF scales, Working Memory, Plan/Organize and Inhibit, loaded on a single factor rather than with the objective measures purported to tap those processes. Gioia, Isquith, Retzlaff and Espy (2002) found that the parent BRIEF scores resulted in a 3-factor model with moderately high correlations between the factors (.84, .64, & .63). The authors describe the BRIEF as a molar-level focus on executive functions and that identifying more discrete processes of executive functions "may be reduced with this more global approach" (Gioia et al., p. 255). Further research is needed to examine the relationship of the BRIEF to other executive function measures. Given these results, when interpreting the BRIEF, clinicians may want to use caution when considering specific subscales.

Limitations

There were several limitations of this study that need to taken into consideration when interpreting the results. The types of analyses pursued (EFA and CFA) require large sample sizes. This sample was smaller than most researchers would consider using for those analyses. However, the analyses were conducted with the knowledge that the results would not be generalized and would be exploratory in nature. Curran et al. (1996) found that with normally distributed data with a sample size of 100, the Maximum Likelihood (ML) estimation procedure incorrectly rejected 5.5% of correctly specified models. With moderately univariate skewed data (skewness=2; kurtosis=7) 20% of correctly specified models were rejected. The inflated Type I error can lead to model rejection or modification when it was correct. When models are misspecified, the Type I error increases. For inclusion errors (N=100), 9.6% were rejected. Models with exclusion errors were falsely rejected at 54.3%. When both types of errors were misspecified, 49% of correct models were rejected incorrectly. This bias in the measurement for ML procedures suggests that with N=100 there may not be enough power to detect a correct model. Decreased normality data characteristics further increase the bias (Curran et al., 1996).

The use of CFA following exploratory analysis with the same sample is not recommended (Mueller, 1997). This is a preliminary investigation, and given the sample size and lack of a split sample, these results should be replicated with a larger sample. Cross-validation with the use of new samples or split samples is preferred. Therefore, the results should be interpreted with great caution. Mueller (1997) discusses basic principles of SEM procedures. With improved statistical programs and their interfaces, SEM procedures are more accessible to researchers who may not have in depth knowledge of SEM. There are three types of SEM research: model testing, model comparisons, and model generation. In this study, model testing indicated that the constructs as proposed based on literature review did yield an approximation of reality or a Type 1 error may have occurred. Model comparisons are theoretically derived models that are compared. Finally, model generation is making data driven modifications. Mueller (1997) cautions novice users of SEM against using model generation. Models can be derived that fit a particular data set; however, they may not have anything to contribute to theory building.

Next, the age range of the children was large (9 years to 16 years of age). The role of development may result in systematic differences between children in different stages of development with ADHD. The interaction of development and ADHD may affect the comorbidities, the severity of symptoms experienced, the treatment history, and the neurobiology of the disorder. Future research should examine age and developmental effects with children with ADHD.

Another limitation is that the no diagnosis group may not have been representative of normal controls. Parents that are willing to include their children in a study that requires at least 9 hours of testing and approximately three appointments may have issues or concerns about their children. Although, an extensive battery of neuropsychological tests were administered to assist in differential diagnosis, it is possible that children in the no diagnosis group had sub-clinical levels of difficulties but did not reach a clinically significant level and were not placed in a clinical group. Additionally, this study did not examine the effects of comorbid diagnoses in either the ADHD or other clinical groups and the effects on the variables of interest.

Other possible limitations due to sample characteristics include the fact that the sample was comprised of children and youth who lived in a small urban community that is greatly influenced by the presence of a large university. Evaluations were conducted in a university clinic and efforts to recruit a variety of children were used; however, the mean of parental educational attainment was fairly high at 15 years or about 3 years of college. This sample may not be representative of children from families with lower levels of parental educational attainment.

Another significant limitation is related to the measures that were selected. Although the measures were selected based on literature review and previous factor analytic studies, the measures selected most likely were not clean measures of the processes of interest (inhibition, working memory, attention, and planning). An important confounding factor is the presence of a good deal of overlap in the definitions provided with models reviewed. The models reviewed were limited in their ability to define and operationalize constructs.

Future Directions

This study did not evaluate the role of development on executive function or ADHD. Future research in the area of the developmental trajectories in normal and disordered executive function would be helpful in understanding these processes. Using latent analyses to examine the underlying structure at different stages in development may assist in refining current theories as they apply to children and youth. In addition, the role of comorbid disorders in children with ADHD was not examined. Continued research considering comorbid disorders and their impact in children with ADHD may also further our understanding of the etiology involved and may improve treatment outcomes.

Several new neuropsychological batteries have been developed to assess children. These batteries were designed with children in mind rather extending tests designed for use with adults to children. These new measures should be utilized in research to investigate their potential contribution to our understanding of normal and disordered executive function processes. It is unknown whether these newly developed tests and batteries would yield cleaner measures of the executive processes of interest in this study.

Given the limitations of this study with regard to sample size, the use of latent variable analyses to investigate processes involved in ADHD should be pursued with larger samples. However, the nature of ADHD, such that the disorder has a good deal of overlap in symptomology with other disorders creates a need for extensive neuropsychological batteries to assist in differential diagnosis. The batteries are labor and time intensive. Latent variable analyses appear to offer utility in understanding of executive processes; however, they require large samples. The continued use of Monte Carlo studies to investigate the utility and limitations of using latent variable analysis is greatly needed. More information regarding the limits and validity with smaller samples would be helpful.

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APPENDIX A

DSM-IV-TR CRITERIA FOR ATTENTION-DEFICIT/HYPERACTIVITY DISORDER

Individual must criteria for either inattention (1) or hyperactivity (2):

(1) six (or more) of the following symptoms of inattention have persisted for at least 6 months to a degree that is maladaptive and inconsistent with developmental level:

Inattention

(a) often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities

(b) often has difficulty sustaining attention in tasks or play activities

(c) often does not seem to listen when spoken to directly

(d) often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (not due to oppositional behavior or failure to understand instructions)

(e) often has difficulty organizing tasks and activities

(f) often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)

(g) often loses things necessary for tasks or activities (e.g., toys, school assignments, pencils, books, or tools)

(h) is often easily distracted by extraneous stimuli

(i) is often forgetful in daily activities

(2) six (or more) of the following symptoms of hyperactivity-impulsivity have persisted for at lest 6 months to a degree that is maladaptive and inconsistent with developmental level:

Hyperactivity

(a) often fidgets with hands or feet or squirms in seat

(b) often leaves seat in classroom or in other situations in which remaining seated is expected

(c) often runs about or climbs excessively in situations in which it is inappropriate (in adolescents or adults, may be limited to subjective feelings of restlessness)

(d) often has difficulty playing or engaging in leisure activities quietly

(e) is often “on the go” or often acts as if “driven by a motor”

(f) often talks excessively

Impulsivity

(g) often blurts out answers before questions have been completed

(h) often has difficulty awaiting turn

(i) often interrupts or intrudes on others (e.g., butts into conversations or games)

A. Some hyperactive-impulsive or inattentive symptoms that caused impairment were present before age 7 years.

B. Some impairment from the symptoms is present in two or more settings (e.g., at school [or work] and at home).

C. There must be clear evidence of clinically significant impairment in social, academic, or occupational functioning.

D. The symptoms do not occur exclusively during the course of a Pervasive Developmental Disorder, Schizophrenia, or other Psychotic Disorder and are not better accounted for by another mental disorder (e.g., Mood Disorder, Anxiety Disorder, Dissociative Disorder, or a Personality Disorder).

Code based on type:

314.01 Attention-Deficit/Hyperactivity Disorder, Combined Type: if both Criteria A1 and A2 are met for the past 6 months

314.00 Attention-Deficit/Hyperactivity Disorder, Predominantly Inattentive Type: if Criterion A1 is met but Criterion A2 is not met for the past six months

314.01 Attention-Deficit/Hyperactivity Disorder, Predominantly Hyperactive-Impulsive Type: if Criterion A2 is met but Criterion A1 is not met for the past six months

Coding note: For individuals (especially adolescents and adults) who currently have symptoms that no longer meet full criteria, “In Partial Remission” should be specified.

314.9 Attention-Deficit/Hyperactivity Disorder Not Otherwise Specified

This category is for disorders with prominent symptoms of inattention or hyperactivity-impulsivity that do not meet criteria for Attention-Deficit/Hyperactivity Disorder.

APPENDIX B

CORRELATIONS BETWEEN OBSERVED VARIABLES

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Stroop	--															
2. CCPT-II Com.	.09	--														
3. GDS V/Com.	.03	.47	--													
4. BRIEF-Inhibit	.08	-.09	-.03	--												
5. Digits	.16	-.17	.16	.01	--											
6. CMS-Seq.	.32	-.11	-.17	.09	.34	--										
7. Letter Fluency	.21	-.06	-.01	.05	.17	.39	--									
8. BRIEF-WM	.28	-.03	-.04	.65	.02	.18	.11	--								
9. TOL^{DX}-TT	-.02	-.04	.06	-.15	.20	.17	.20	-.17								
10. TOL^{DX}-TM	.10	.12	.16	-.01	.01	.21	.02	-.07	.38	--						
11. WCST-Cat.	-.02	-.06	.07	.01	.01	.07	.22	-.02	.19	.12	--					
12. BRIEF-Plan	.31	.04	-.02	.69	-.02	.13	.04	.81	-.12	-.02	.02	--				
13. GDS Dist.	.05	-.01	.32	.06	.12	.18	.15	.00	.17	.18	.27	-.01	--			
14. GDS V/Correct	-.01	.18	.57	.01	.14	.11	.09	.08	.15	.14	.19	.03	.45	--		
15. CCPT-II Om.	.24	.31	.26	.10	.01	.08	.08	.14	-.06	-.02	.23	.05	.32	.27	--	
16. WCST-FtM	.24	-.18	-.10	.11	.04	.17	.23	.21	-.18	-.10	.22	.22	-.14	-.04	.00	--

Note. Significant correlations ($p < .05$) are in bold; Stroop=Stroop Color-Word score; CCPT-II Com.= CCPT-II Commission errors; GDS V/Com.=GDS Vigilance Commission errors; BRIEF Inhibit=BRIEF Inhibit Scale; Digits=WISC-III Digits Backward; CMS-Seq.=CMS Sequences subtest; BRIEF-WM=BRIEF Working Memory Scale; TOL^{DX}-TT=Tower of London^{DX} Total time; TOL^{DX}-TM=Tower of London^{DX} Total moves; WSCT-Cat.=WCST Categories Obtained; BRIEF-Plan=BRIEF Plan/Organize Scale; GDS Dist.=GDS Distractibility; GDS V/Correct=GDS Vigilance Correct; CCPT-II Om.=CCPT-II Omission errors; WCST-FtM=WCST Failure to maintain set.

APPENDIX C

RESULTS OF EFA ANALYSES

Constrained EFA with 16 Variables and 4 Factors.

	Factor				
Measures	1	2	3	4	Unique Variance
CCPT-II Com.	.99	-.05	-.08	>.01	.00
CCPT-II Om.	.32	.09	.10	-.29	.80
BRIEF-Plan	.08	.92	.02	.01	.15
BRIEF-WM	.01	.88	.08	-.03	.22
BRIEF-Inhibit	-.05	.74	-.02	-.05	.44
WCST-FtM	-.15	.24	.17	.06	.89
CMS-Seq	-.04	.13	.86	-.03	.24
Letter Fluency	-.02	.06	.45	-.12	.78
Digits Backward	-.14	-.01	.35	-.24	.80
Stroop	.13	.29	.35	.01	.78
TOL^{DX}-TT	-.03	-.18	.25	-.20	.86
TOL^{DX}-TM	.13	-.06	.23	-.18	.89
GDS V/Correct	.19	.03	.08	-.75	.40
GDS V/Com.	.44	-.05	-.17	-.64	.36
GDS Dist.	>.01	-.01	.17	-.59	.63
WCST-Cat.	-.05	>.01	.12	-.27	.91

Note. CCPT-II Com.= CCPT-II Commission errors; CCPT-II Om.=CCPT-II Omission errors; BRIEF-Plan=BRIEF Plan Scale; BRIEF-WM=BRIEF Working Memory Scale; BRIEF-Inhibit=BRIEF Inhibit Scale; WCST-FtM=WCST Failure to Maintain Set; CMS-Seq.=CMS Sequences subtest; Digits=WISC-III Digits backward; Stroop=Stroop Color-Word score; TOL^{DX}-TT=Tower of London^{DX} Total time; TOL^{DX}-TM=Tower of London^{DX} Total moves; GDS V/Correct=GDS Vigilance Correct; GDS V/Com.=GDS Vigilance Commission errors; GDS Dist.=GDS Distractibility; WSCT-Cat.=WCST Categories Obtained.

Unconstrained EFA with 16 Variables.

	Factor						
Measures	1	2	3	4	5	6	Unique Variance
CCPT-II Com.	.96	.23	-.02	-.10	-.03	.07	.00
GDS V/Com.	.25	.94	-.02	-.07	.22	.07	.00
BRIEF-Plan	.06	.01	.94	.11	-.05	-.01	.09
BRIEF-WM	.02	-.01	.84	.19	.04	-.14	.24
BRIEF-Inhibit	-.06	-.02	.74	.01	.09	-.07	.44
CMS-Seq.	-.01	-.18	.07	.70	.16	.22	.39
Letter Fluency	-.01	-.02	.01	.48	.17	.09	.74
Stroop	.14	.04	.24	.47	.01	-.05	.70
Digits Backward	-.19	.23	-.05	.42	.03	.13	.71
WCST-FtM	-.13	-.01	.18	.34	-.08	-.25	.77
GDS Dist.	-.04	.18	.02	.05	.69	.18	.45
CCPT-II Om.	.34	.09	.05	.13	.51	-.20	.56
GDS V/Correct	.09	.47	.04	.07	.47	.14	.53
WCST-Cat.	-.06	.01	.02	.08	.36	.11	.85
TOL^{DX}-TT	-.08	.02	-.13	.11	.11	.64	.55
TOL^{DX}-TM	.07	.09	-.02	.08	.10	.53	.69

Note. CCPT-II Com.= CCPT-II Commission errors; GDS V/Com.=GDS Vigilance Commission errors; BRIEF-Plan=BRIEF Plan/Organize Scale; BRIEF-WM=BRIEF Working Memory Scale; BRIEF-Inhibit=BRIEF Inhibit Scale; CMS-Seq.=CMS Sequences subtest; Stroop=Stroop Color-Word score; Digits backward=WISC-III Digits backward; WCST-FtM=WCST Failure to Maintain Set; GDS Dist.=GDS Distractibility; CCPT-II Om.=CCPT-II Omission errors; GDS V/Correct=GDS Vigilance Correct; WSCT-Cat.=WCST Categories Obtained; TOL^{DX}-TT=Tower of $London^{DX}$ Total time; TOL^{DX}-TM=Tower of $London^{DX}$ Total moves.

Unconstrained EFA with 13 Variables (BRIEF Scales removed)

	Factor						
Measures	1	2	3	4	5	6	Unique Variance
GDS V/Com.	.93	.06	-.10	.27	-.02	.21	.00
GDS V/Correct	.49	.12	.10	.07	-.01	.45	.53
TOL^{DX}-TT	.02	.99	.04	-.09	-.01	.05	.00
TOL^{DX}-TM	.11	.37	.17	.08	-.07	.10	.80
CMS-Seq.	-.09	.13	.98	-.06	.05	.10	.00
Digits Backward	.26	.17	.34	-.22	.02	-.02	.74
Letter Fluency	-.01	.19	.34	-.03	.30	.16	.73
Stroop	.03	-.02	.32	.13	.23	.04	.82
CCPT-II Com.	.21	.04	-.03	.94	-.10	.02	.07
WCST-FtM	-.02	-.18	.15	-.09	.76	-.07	.35
GDS Dist.	.20	.11	.11	-.09	-.11	.72	.40
CCPT-II Om.	.09	-.06	.07	.31	.08	.47	.66
WCST-Cat.	-.01	.17	-.01	-.04	.35	.42	.68

Note. GDS V/Com.=GDS Vigilance Commission errors; GDS V/Correct=GDS Vigilance Correct; TOL^{DX}-TT=Tower of $London^{DX}$ Total time; TOL^{DX}-TM=Tower of $London^{DX}$ Total moves; CMS-Seq.=CMS Sequences subtest; Digits Backward=WISC-III Digits backward; Stroop=Stroop Color-Word score; CCPT-II Com.=CCPT-II Commission errors; WCST-FtM=WCST Failure to Maintain Set; GDS Dist.=GDS Distractibility; CCPT-II–Om.=CCPT-II Omission errors; WSCT-Cat.=WCST Categories Obtained

Unconstrained EFA with 12 Variables (BRIEF scales and GDS Vigilance Commissions removed).

	Factors				
Measures	1	2	3	4	Unique Variance
CCPT-II Om.	.78	.14	.06	-.18	.34
CCPT-II Com.	.44	-.10	.02	.16	.77
GDS V/Correct	.36	.06	-.32	-.18	.74
CMS-Seq.	-.02	.72	-.23	-.04	.43
Stroop	.19	.52	.14	.02	.67
Letter Fluency	-.02	.46	-.13	-.27	.70
Digits Backward	-.05	.38	-.22	.01	.80
TOL^{DX}-TT	-.08	.10	-.60	-.09	.61
TOL^{DX}-TM	.03	.12	-.44	-.02	.80
GDS Dist.	.38	.10	-.40	-.22	.64
WCST-Cat.	.12	>.01	-.19	-.72	.44
WCST-FtM	-.19	.35	.41	-.43	.48

Note. CCPT-II Om.=CCPT-II Omission errors; CCPT-II Com.=CCPT-II Commission errors; GDS V/Correct=GDS Vigilance Correct; CMS-Seq.=CMS Sequences subtest; Stroop=Stroop Color-Word score; Digits Backward=WISC-III Digits backward; TOL^{DX}-TT=Tower of London^{DX} Total time; TOL^{DX}-TM=Tower of London^{DX} Total moves; GDS Dist.=GDS Distractibility; WSCT-Cat.=WCST Categories Obtained; WCST-FtM=WCST Failure to Maintain Set
.

Constrained EFA with 12 Variables (BRIEF scales and GDS Vigilance Commissions removed).

	Factors			
Measures	1	2	3	Unique Variance
CCPT-II Om.	.78	.15	.11	.37
GDS Dist.	.46	.10	-.39	.63
GDS V/Correct	.43	.04	-.33	.70
CCPT-II Com.	.39	-.18	.06	.82
WCST-Cat.	.25	.19	-.19	.87
CMS–Seq.	>.01	.64	-.26	.53
Letter Fluency	.04	.53	-.18	.69
Stroop	.17	.47	.10	.74
WCST-FtM	-.10	.45	.27	.72
Digits Backward	-.04	.35	-.24	.82
TOL^{DX}-TT	-.03	.07	-.63	.59
TOL^{DX}-TM	.06	.05	-.46	.78

Note. CCPT-II Om.=CCPT-II Omission errors; GDS Dist.=GDS Distractibility; GDS V/Correct=GDS Vigilance correct; CCPT-II Com.=CCPT-II Commission errors;.WSCT-Cat.=WCST Categories obtained; CMS-Seq.=CMS Sequences subtest; Stroop=Stroop Color-Word score; WCST-FtM=WCST Failure to Maintain Set; Digits Backward=WISC-III Digits backward; TOL^{DX}-TT=Tower of $London^{DX}$ Total time; TOL^{DX}-TM=Tower of $London^{DX}$ Total moves.

Unconstrained EFA with 11 Variables (BRIEF scales, GDS Vigilance Commissions and GDS Vigilance Correct removed).

	Factors				
Measures	1	2	3	4	Unique Variance
CCPT-II Om.	.95	-.23	.19	.08	.00
CCPT-II Com.	.38	.11	-.11	-.02	.83
WCST-Cat.	.05	-.82	>.01	-.18	.30
CMS-Seq.	-.05	-.03	.72	-.22	.43
Stroop	.15	.01	.50	.10	.72
Letter Fluency	-.06	-.25	.47	-.11	.70
Digits Backward	-.05	.02	.39	-.19	.81
TOL^{DX}-TT	-.06	-.11	.11	-.61	.60
WCST-FtM	-.21	-.38	.37	.46	.47
TOL^{DX}-TM	-.01	-.05	.12	-.45	.78
GDS Dist.	.29	-.22	.12	-.33	.74

Note. CCPT-II Om.=CCPT-II Omission errors; CCPT-II Com.=CCPT-II Commission errors; WSCT-Cat.=WCST Categories Obtained; CMS-Seq.=CMS Sequences subtest; Stroop=Stroop Color-Word score; Digits Backward=WISC-III Digits backward; TOL^{DX}-TT=Tower of $London^{DX}$ Total time; WCST-FtM=WCST Failure to Maintain Set; TOL^{DX}-TM=Tower of $London^{DX}$ Total moves; GDS Dist.=GDS Distractibility.

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